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NUMBER 6

MEMOIR ON THE IMMEDIATE CAUSE OF BUNT OR SMUT OF WHEAT, AND OF SEVERAL OTHER DISEASES OF PLANTS, AND ON PREVENTIVES OF BUNT

By

BÉNÉDICT PRÉVOST

Mémoire sur la cause immédiate de la carie ou charbon des blés, et de plusieurs autres maladies des plantes, et sur les préservatifs de la carie. 1807.

Translated from the French

by

GEORGE WANNAMAKER KEITT

With a Foreword, Biographical Sketch, and Evaluation of the Memoir by the Translator

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MÉMOIRE

SUR LA CAUSE IMMÉDIATE

DE LA CARIE OU CHARBON DES BLÉS,

ET DE PLUSIEURS AUTRES MALADIES DES PLANTES,

ET SUR LES PRÉSERVATIFS DE LA CARIE.

PAR M. BÉNÉDICT PRÉVOST,

Membre de la Société de Physique et d'Hist. Nat. de Genève, de celle des Naturalistes de la même ville, et de la Société des Sciences et des Arts du département du Lot, séante à Montauban;
Correspondant de la Société Galvanique et d'Électricité de Paris, des Sociétés Médicale et de Méd. Prat. de Montpellier, de celle des Amateurs des Sciences de Lille, et d'Émulation de Lausanne.

C'est une botanique à faire, que celle des plantes microscopiques.
SENEBIER, *Physiol. Vég.* T. II. p. 291.

A PARIS,
CHEZ BERNARD, IMPRIMEUR-LIBRAIRE. QUAI DES AUGUSTINS, N.° 25.

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FOREWORD AND ACKNOWLEDGMENTS

IN TRANSLATING a work of so much historical significance as characterizes the Memoir that follows, it has seemed more desirable to seek to retain as much as feasible of the mode of statement of the author than to convey his essential ideas in the style of another. The original text has, therefore, been followed as closely as seemed consistent with rendition in acceptable English. While an attempt has been made to eliminate the more glaring Gallicisms, constructions more characteristic of French than English have been retained in many instances in order to avoid the necessity of extensive recasting of the language. It is hoped that gain in fidelity to the original statement will more than compensate for the sacrifices sometimes imposed on the quality of the English.

Grateful acknowledgements are made:

To each, Mrs. T. C. Ryker and Dr. J. Dufrénoy, for comparing the translation with the original and offering many helpful suggestions for improvement of the English rendition;

To each, Dr. L. R. Jones, Dr. J. Dufrénoy, and Dr. H. B. Humphrey, for criticism of the sketch of the life of Bénédict Prévost and of the "evaluation" of the Memoir;

To the Lloyd Library for loan of the original copy of the Memoir and to the Princeton University Library for loan of the biographical sketch of Bénédict Prévost by Pierre Prévost (see footnote 1, p. 7);

And especially to Dr. H. B. Humphrey for comparing the translation with the original and critically editing it, the biographical sketch, and the "evaluation."

THE TRANSLATOR.

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ISAAC-BÉNÉDICT PRÉVOST[1]
1755–1819

BÉNÉDICT PRÉVOST came of an old, intellectual family of Geneva, Switzerland. His parents, Jean-Jacques and Marie-Elizabeth Henri Prévost, were people of admirable qualities but limited means. They had two children, Isaac-Bénédict, born at Geneva, August 7, 1755, and a daughter, who died, unmarried, in early womanhood.

Bénédict's early education was very irregular. He had little inclination for the studies of grammar school, and was placed in a boarding school of a small neighboring village, where he received only very limited instruction. He undertook successively two apprenticeships, one in engraving and the other in commerce. He gave up the latter, which offered flattering prospects, to cultivate the sciences. In October, 1777, at the age of 22, he accepted the position of tutor of the sons of M. Delmas of Montauban, Département du Lot, France. This city came to be his second home, to which he was held for the rest of his life by ties

[1] Prévost, Pierre. Notice de la Vie et des Écrits d'Isaac-Bénédict Prévost, 110 pp. Genève, 1820.

The following brief account of the life and works of Bénédict Prévost is drawn from this book by his cousin and life-long intimate friend and correspondent. Pierre Prévost's account is written with such authenticity, charm, and sympathetic understanding that it is abridged with as little change as possible, many passages being used in translation.

Abraham Prévost of Geneva, teacher ("principal du collège") and pastor, had two sons. The older became a lawyer of distinction. Pierre, the younger, born in 1751, became a distinguished scholar in the fields of literature, philosophy, and the natural sciences. In 1780 he was appointed by Frederick II of Prussia to the Academy of Sciences at Berlin, where he also held a professorship in an academy for young gentlemen. Though he was highly successful in this work, his love and loyalty for his family and country were such that, in 1784, he accepted the chair of Belles-Lettres at the Academy of Geneva, though the stipend was hardly a third of that at Berlin. Here he completed his long and distinguished career. (Cherbuliez, A. Discours sur la Vie et les Traveaux de feu Pierre Prévost, ancien Professeur de Philosophie à l'Académie de Genève, 64 pp. Genève, 1839.)

of friendship and by congenial opportunities for study and teaching.

At the time of his arrival at Montauban, Prévost had acquired little science; but he was very apt in learning it, and had especial talent and taste for mathematics. His progress was rapid. After two years he formed and announced the intention of devoting himself entirely to his studies. Though the very attractive positions of his cousin, Pierre Prévost, at Berlin were open to him when the former resigned to return to Geneva in 1784 (see footnote 1, p. 7), he preferred the friendships and the work that had become so dear to him at Montauban. He then persuaded his friends to refrain from seeking further offers for him.

The earlier phase of his studious career was concerned chiefly with mathematics. Physics and natural history dominated later.

In the study of natural history he had many obstacles to overcome, but also enjoyed some peculiar advantages. He spent part of the year in the country, the principal theater of his observations. There he found, in his adopted family, friends who shared his tastes and took pleasure in furthering his work. But the number was limited, and even in the city he did not find all the help that might have favored his enterprises. He had difficulty in procuring the books that he needed. The irregularities of his early studies served, perhaps, to arouse his curiosity; but they slowed his progress. He supplied by his genius and enthusiasm what he lacked in this regard, and his generous efforts were crowned by success.

His relations and literary correspondence multiplied. His correspondence with his cousin, Pierre Prévost, was never interrupted, and became for both a source of gentle and useful pleasure. At Montauban he was affiliated with *l'Académie du Lot*, of which he was one of the founders. He enjoyed the friendship of many members of this learned society. He had continuing relations, among others, with the able astronomer, le Duc la Chappelle. His pupils became his friends. At Geneva, MM. LeSage, Senebier, Jurine, Gosse, Huber, and Maunoir corresponded with him. Other learned societies that honored him with membership appear on the title pages of this translation and of the account of his life by Pierre Prévost (Loc. cit.).

Besides the memoirs that he read before the Academy at

Montauban, he published others through various scientific channels. Thus, by assiduous work, he laid the foundation of a solid reputation, gaining enjoyment from his discoveries and the continuous increase of his knowledge.

For him, the ardor for study did not at all interfere with the charms of friendship. The gentleness of his dealings, his amiable gaiety, the sureness of his character and his principles, endeared him to all with whom he had associations. The very manner in which he had acquired his great knowledge contributed to its value. He was self-taught. Everything in his writings and his discourse was marked with the stamp of originality. He had invented what he learned; and, although long accustomed to draw from books instruction that he well knew how to appreciate, he always did this work in an active manner, meditating, repeating observations, varying experiments, judging his masters freely, and recognizing in the last resort nothing but his reason and nature.

Content to follow his tastes and the development of his interests in a quiet activity, Bénédict Prévost thought little of the avenue. But his friends thought for him. A protestant academy (*Faculté de Théologie protestante*) was founded at Montauban. There was needed a professor capable of filling with dignity the chair of philosophy. All eyes turned to Bénédict Prévost. The position was offered him, and after careful consideration he accepted it (in 1810). Thenceforth, he directed all his efforts towards the instruction with which he had been charged. He endeared himself to his students and was truly devoted to them. His courses were followed eagerly and fruitfully.

On June 10, 1819, at the age of 64, after a short illness, Bénédict Prévost died at Montauban in the home of M. Delmas, universally regretted.

The works of this remarkable man are listed and discussed by Pierre Prévost (Loc. cit.). More than a score of papers were published in the following channels: *Annales de Chimie, Annales de Chimie et de Physique, Bibliothèque britannique, Bibliothèque universelle, Journal de Physique,* and *Annales de la Société pratique de Montpellier.* His unpublished works were still more extensive. The subjects that he treated covered a broad scope, including physics, chemistry, biology, and philosophy.

Bénédict Prévost's most important contribution is the Memoir here translated. It is sad to record that this beautiful work, the crowning achievement of a life so singularly devoted to the advancement of knowledge, was denied fitting appreciation[2] during the life of its author. Following the presentation of this paper at Montauban in 1807, the Society published it and sent it to the Institute, which appointed a Commission to examine it and make a report. M. Tessier, reporter for this Commission, "lauded the zeal, the acuteness, even the talent, of M. Bénédict Prévost in microscopic observations, but he did not at all recognize the strides of genius that he had taken along a course in which men of the highest merit had hitherto but groped."[3] This cold indifference, suffered from a body so well informed and justly celebrated, would have profoundly depressed a less modest man than Bénédict Prévost; but, far from protesting against this denial of justice, he made a law of silence, and imposed it, even to his last moments, upon his many friends. However, the preventive that he recommended constantly guaranteed the crops of proprietors who used it with care. His Memoir[4] penetrated into Belgium, England, and other countries, and foreigners profited by a discovery made in France, before the prejudices in favor of the old methods gave way. So it was that vaccination found apologists long after the discovery of vaccine.

A further discussion of the significance of the Memoir is given in the following "evaluation" by the translator.

G. W. Keitt.

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[2] The following statements are drawn from an article quoted by Pierre Prévost (Loc. cit.) from *Journal du Tarn et Garonne*, July 21, 1819.

[3] All quotations in this sketch and the appended evaluation of the Memoir are given in translation.

[4] Pierre Prévost (Loc. cit.) states that a very good abstract of the Memoir appeared in *Recueil agronomique de la Société des Sciences de Tarn et Garonne*, September, 1820.

AN EVALUATION OF THE MEMOIR BY THE TRANSLATOR

IN THE FOLLOWING Memoir, Bénédict Prévost clearly showed "that the immediate cause of bunt is a plant of the genus of the uredos or of a very nearly related genus." So far as the translator is aware, this work contains the first recorded adequate experimental demonstration and interpretation of the rôle of a microörganism in the causation of a disease. It establishes one of the most fundamental and fruitful scientific concepts and lays a firm foundation for the later and more generalized germ theory of disease. The Memoir contains many other contributions of outstanding merit, but this alone entitles it to recognition as one of the most significant pioneer works in the field of biology.

Prévost's contribution bears critical examination. Founded upon able, painstaking experimentation over a ten-year period in the prime of his life, his essential findings stand unchanged. He gave a detailed and accurate description of the symptoms of bunt in the various macroscopic stages of its development (¶1–8, 29–33). He noted the constant occurrence of "globules" in the bunted kernels and rightly suspected and proceeded to prove that they were the "seeds," "gemmae" or "spores" of a cryptogam (¶2, 5, 10–13). He described and illustrated these spores in detail (¶5–7, 24–27, 52; Pl. 1) and made extensive studies of their germination and the development of the "bunt plant" in relation to time, temperature, substrata, toxic agents, age and previous treatment of the spores, concentration of the spores, etc. (¶11–28, 41–43, 50, 52–56, 109–113, 121–128, 130, 138–158, 188; Pl. 1). Having concluded that he was dealing with a microscopic plant "of the genus of the uredos or a very nearly related genus" (¶102), he proceeded by extensive and successful inoculation experiments to prove that it is the "immediate cause" of bunt and to define conditions that favor or hinder infection (¶57, 104–128, 137). He pointed out "that the vegetation of this

plant, as well as that of the majority of the uredos, begins in the open air and is completed in the interior of the plant that it attacks" (¶102), suggesting for such organisms "the general denomination of *internal parasitic plants*" (¶103). He observed germinated spores of the bunt organism in the soil (¶107, footnote) and on the surface of wheat seedlings grown in infested soil (¶43). Though he did not succeed in observing the mode of penetration of the bunt fungus into the wheat plant or its growth to the wheat embryo, he correctly surmised (¶46) that some ramifications of the bunt plant must penetrate into the very young wheat plant and later insinuate themselves into the embryo and fructify (¶41–58). He observed the bunt plant after it reached the wheat embryo and described its fructification there (¶33–40, 91, 93). He was unable to trace the details of the earlier stages in the formation of the gemmae and had an erroneous idea regarding the development into gemmae of some of the smaller granules that he took to be their initials. However, he correctly recognized the more advanced young gemmae (Pl. 2) and found that they germinated typically (¶36). In extensive and refined toxicological studies (¶126–130, 138–156) he found that certain copper salts, distilled water in which metallic copper had been left under suitable conditions, and various other substances in solution would prevent the germination of spores of the bunt fungus. He critically distinguished injurious and inhibitory from lethal effects and experimented extensively on relations of concentration of the toxic agent, time, and temperature to toxic effects. On the basis of the information thus obtained and of his extensive knowledge of the disease, he proceeded to experiment on the control of bunt. He made suitably controlled large-scale field tests in which inoculated seed wheat was planted after having received various treatments. Spores of the bunt organism from the treated seed were tested for germination, and data were taken on the development of the disease on the wheat grown in the field from the experimental seed. Excellent control of the disease was obtained by steeping the seed wheat in a copper sulphate solution, and detailed practical recommendations were made for performing this operation on a large scale (¶157–181).

In basic method and in interpretation, Prévost's work is sur-

prisingly modern in the best sense of the word. Throughout his investigation he consistently used the best approach that has yet been found to the secrets of nature, the experimental method skillfully applied from the point of view of history of development. His work is remarkably comprehensive and well correlated and lays the foundation for nearly all major branches of modern plant pathology.

Prévost's more detailed techniques were in keeping with the quality and principles of his general plan. The methods that he developed for growing the bunt fungus in water culture, for example, were far ahead of his time. He controlled the quality of the water with reference to source, purity, and sterility; the quality of spores with regard to source, age, and previous treatment; and the conditions of the experiments with regard to such factors as temperature, moisture, availability of oxygen, quantity of spores and of water, and introduction of a wide variety of chemical compounds for study of their toxicity in terms of injurious, inhibitory, or lethal effects (¶41–43, 109–113, 121–128, 130, 138–158, 188). He developed effective methods for minimizing contamination in the spore suspensions that he prepared for these experiments, using in part the principle of dilution. He clearly recognized the occurrence of contamination of cultures by air-borne spores or microörganisms and devised ingenious methods for its prevention (¶41). Here was laid an excellent foundation for the pure culture of microörganisms *in vitro* (¶103).

An example of Prévost's technical thoroughness and penetrating insight is found in his discussion of effects of "hard" water on the fungicidal action of dilute solutions of copper sulphate (¶152–153). He calls attention to the formation of a precipitate at the expense of the copper sulphate "in greater proportion as its [the copper sulphate's] quantity in relation to that of the water is reduced; so that, *if a very weak solution is filtered, the liquid that passes through does not produce nearly so great an effect.* . . . Does the precipitate act upon the bunt; or, indeed, *could the filter act upon the sulphate?* However it be, the precipitate and the solution in which it is suspended act, together or separately, upon all the bunt that the solution is capable of completely wetting." [The italics are added.] While he did

not solve the problem of whether the filter acts upon copper sulphate, he clearly recognized and defined it. It is now easily demonstrated that the filter may retain most of the copper of a small quantity of dilute copper sulphate solution by adsorption. Many workers who followed Prévost in studies of the toxicity of copper fungicides failed to take this vitally important question into account. Much of the resulting confusion could have been avoided if his pioneer work had received the attention that it deserved. Furthermore, suitable studies of the fungicidal properties of Prévost's precipitate, which is closely related to the essential components of Bordeaux mixtures and their weathered residues, might well have hastened by many decades the discovery of fungicides of this type.

Prévost's interpretations are critical and discriminating and worthy of the quality of his experimentation. His conclusions are rigorously based on experimental proofs. In treating some questions concerning which the experimental evidence was incomplete, chiefly in relation to diseases that he necessarily studied less intensively than bunt (¶59–102), he justifiably uses analogy, some of which proved to be erroneous. However, when he resorts to analogy he does it frankly and deceives neither his reader nor himself regarding the basis of the reasoning (e.g., ¶ 102). His work on other diseases (¶59–102) was incidental, and the quality of much of it is far below that of his essential contribution, the study on bunt.

His conception of parasitic disease is remarkably comprehensive and discriminating. He points out that the internal parasitic bunt plant is the immediate cause of the disease but makes it equally clear that the parasite can induce the disease only under sufficiently favorable conditions (¶104–128 and 137). In his title he refers to the bunt plant as the "immediate cause" of the disease, and in the text he usually speaks of it as the "immediate" or "direct" cause. However, having clearly established the qualifications that attach to the causal rôle of the organism in relation to the disease, he does not hesitate in later passages to speak of the bunt plant as the "cause" of the disease. Prevost's usage deserves the careful consideration of those who are interested in clarity of concept and preciseness of terminology regarding these relations, which are so fundamental to general pathology.

A perusal of Prévost's Memoir will reward one with many interesting by-products of his pioneering. His description of indirect germination of the "uredo with white dust" from *Portulaca* (¶95) is probably, as he thought it to be, the first record of this type of germination. In ¶96 is found a vivid and accurate description of what later became known, under a more generalized concept, as Brownian movement. Again, though his mention of the matter is incidental, his increasing knowledge of the development of microscopic plants and "animalcules" (¶95) from pre-existing "gemmae," "spores," or "seeds" leads him to express his disbelief in ideas of spontaneous generation that were then prevalent (¶95 *h*).

Prévost's ideas on the control of bunt are as clear and advanced as his conception of its nature, cause, and epidemiology. The ideal expressed in his closing sentence, . . . "to propagate pure seed, and to extirpate the germ of the infection from the soil of the Empire," should be a lasting inspiration to students of plant disease control. Even with all the splendid achievements of modern plant pathology, how far short we are of this ideal! Of course, there are many obstacles that Prévost could not foresee. But would he have been content to stop, even in the face of great difficulties, with methods that are in so many cases costly, laborious, and uncertain of success and that so often consist of an annually recurring protective program, with little or no attention to "extirpation" of the pathogen? May not some of the brightest chapters in the history of plant-disease control remain to be written on the basis of knowledge gained by pursuit of the ideals and application of the methods of this far-visioned pioneer? May not sufficient application of the experimental method to the study of the phenomena of plant disease from the point of view of detailed history of development reveal new possibilities for supplementing protective programs with such effectiveness that many destructive plant pathogens, even if they are not "extirpated from the soil of the Empire," can be reduced to such low levels of survival that they may be surely and economically controlled, or even eradicated locally or regionally? Surely one should give up such ideals "only when repeated and unsuccessful efforts force him to renounce all hope" (¶9).

In failing to gain due recognition from his generation, Prévost

but shared the common lot of pioneers in the advancement of knowledge. He was too far ahead of his time. The autogenetic theory of disease was dominant in places of authority. Who was this obscure tutor from the provinces that he should challenge the teachings of the Masters?

While it was not given the recognition that it deserved, Prévost's contribution was never entirely overlooked, and undoubtedly had an important influence on later work. It has already been stated (p. 10) that the Memoir was well reviewed in at least two popular journals and that the method of seed treatment became widely known through practice. The Memoir also was cited in botanical literature. Of special importance is the extensive reference made to it by the Tulasnes,[1] with every evidence of confidence in the work and acceptance of its essential conclusions. Such treatment in a major publication by the leading mycologists of the time brought Prévost's work into conspicuous notice. Thereafter, he was widely cited, but chiefly for the germination of fungus spores and the discovery of the fungicidal action of copper sulphate. The full significance of his contribution continued to lack recognition, probably due largely to reliance of later workers upon reviews, the original being very rare.[2] DeBary,[3] for example, in the classical work that is correctly credited with establishing beyond further serious opposition the view that fungi are capable of causing disease in plants, cites reviews and states that the original work was not available.

In contemplating the quality and significance of the work, one's thoughts revert to the man. Then the characterization of the biographer (Pierre Prévost, loc. cit., p. 19–20), already notable for its intimate and sympathetic understanding, reveals a new depth of insight:

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[1] Tulasne, L. R. et C. Mémoire sur les Ustilaginées comparées aux Uredinées. Ann. Sci. Nat., Ser. 3, 7: 12–127. 1847.

[2] To gain information regarding the availability in North America of Prévost's Memoir and of the account of his life by Pierre Prévost (Loc. cit., footnote 1, p. 7) an inquiry was sent to more than 50 libraries that were thought to be the most likely to contain such works. Only one copy of each was located (see acknowledgments, p. 5). Grateful acknowledgment is made to Mr. C. S. Hean, Librarian of the Wisconsin College of Agriculture, for assisting in this search.

[3] DeBary, A. Untersuchungen über die Brandpilze und die durch sie verursachten Krankheiten der Pflanzen mit Rücksicht auf das Getreide und andere Nutzpflanzen, 144 pp. Berlin, 1853.

"For him, the ardor for study did not at all interfere with the charms of friendship. The gentleness of his dealings, his amiable gaiety, the sureness of his character and his principles, endeared him to all with whom he had associations. The very manner in which he had acquired his great knowledge contributed to its value. He was self-taught. Everything in his writings and his discourse was marked with the stamp of originality. He had invented what he learned; and, although long accustomed to draw from books instruction that he well knew how to appreciate, he always did this work in an active manner, meditating, repeating observations, varying experiments, judging his masters freely, *and recognizing in the last resort nothing but his reason and nature.*" [The italics are added.]

Those who cherish the memory of men who have pioneered greatly in the advancement of knowledge and the amelioration of suffering may well pay a full measure of respect and admiration to this modest scholar of Montauban, who made such splendid "strides of genius along a course in which men of the highest merit had hitherto but groped."

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MEMOIR ON THE IMMEDIATE CAUSE OF BUNT OR SMUT OF WHEAT, AND OF SEVERAL OTHER DISEASES OF PLANTS, AND ON PREVENTIVES OF BUNT

THE RAVAGES of bunt are known. It often devastates the country in which I live. I have seen fields in which there were twice as many bunted as healthy heads; and it is not very unusual to find the latter in the proportion of only two or three to one.

MM. Tillet and Duhamel, and later several other authors, especially M. Tessier, have contributed excellent works on this scourge of agriculture, and have indicated various means of protecting the fields from it. But, whether these means were too troublesome or too costly, or whether they did not always measure up to the expectations of those who put them into practice, it is a fact that many proprietors often have their crops infected, although all or nearly all have adopted some procedure of liming, or other preventive methods.

It is this that, in 1797, induced the scientific section of the Society of Montauban, after the reading of a memoir by M. Robert-Fonfrède upon this subject, to invite its members to occupy themselves with it.

Thenceforth, I prepared to respond to this invitation. Every year, on the estate of M. Delmas, near Montauban, I made large-scale experiments of which I shall speak in treating of the preventives of bunt. The first question concerns the immediate cause of this deterioration of the grain, which I discovered in 1804, and of which I have assured myself since by a large number of experiments and observations.

But I shall first give an exact idea of what is called bunt, whether from my own observations or from those of authors who have shed the most light upon this matter.

I

Description of Bunt of Wheat

1. *Bunt*, which in some countries is called *smut*, attacks the interior of the kernels, without changing the nature of the glumes, the petals, or the other parts of the head, which, however, as well as the stalk, it deforms more or less.

2. The germ is destroyed, and the farinaceous substance is replaced by a brown, almost black, powder, which has a very bad odor, especially when it is fresh.

3. The mature heads that bear the bunted kernels do not incline on their stalks, as do the healthy ones; but, because of their light weight, the direction of their axis remains vertical. They are distorted, and the upper part of the stalk, immediately beneath the head, is more or less twisted. In general, the bunted plants are shorter. The heads and leaves have a blackish tint; and it is very noticeable that, not only the straw of the bunted wheat, but that of the healthy wheat mixed with it, is darker than the other.

4. The bunted heads do not flower; the stamens are formed, however, but they are compressed between the glume and the seed, and do not emerge at all, or at least appear only when the wheat is fully ripe, and when by desiccation or some other cause the envelopes fall. The stigmas are present also, but they do not expand as in healthy wheat, or at least expand only very rarely.

5. When the dry powder of bunt is examined under the microscope with a very strong lens, it is seen to be composed of brown, nearly black (Pl. 1, fig. 1), rather uniform, and roughly spherical grains, in which some more or less luminous points are perceived by transmitted light, as if they themselves contained other much smaller grains.

6. As exactly as I could, I measured the diameter of the first grains by means of a glass on which had been drawn the 1/200 parts of a line. The smallest ones appeared to me to equal one of these measures, or 11/1,000,000 meter; and the largest 1/150 line, or 15/1,000,000 meter. A bunted kernel of medium size should, therefore, contain several millions of these grains.

Held for some time in water, they swell a little, and acquire

a more perfect sphericity (Pl. 1, fig. 2). The largest then measure as much as 1/100 line, or 23/1,000,000 meter.

7. These grains or globules for the most part sink rather quickly to the bottom of the water; but, though they are consequently specifically heavier than the liquid, some of them nevertheless stay at the surface, and a bunted kernel of wheat rather generally remains there. Then it often empties itself through some rent, from which the black dust that it contains escapes like a descending smoke.

8. One sometimes finds on the same wheat plant bunted heads and healthy ones; in the same head, healthy and bunted kernels; and the same kernel may be only partly bunted. This last case is rare; however, I succeeded in collecting two or three hundred of these kernels, the majority of which appeared intact on the germ side. I wished to sow them; but, having accidentally lost them, I made up for the deficiency of this experiment in a way that will be seen later.

II

Physiologic Cause of Bunt

9. In making experiments relative to the economic aspect of the question that I had undertaken to solve, I did not fail to apply myself to the direct cause of bunt. I had found in the authors whom I had been able to consult only conjectures upon this interesting point; but no observation, no decisive experiment, or undertaking in the hope of obtaining decisive results.

However, the immediate cause of the trouble once known, it would seem to be very much easier to find a remedy. One should, therefore, give up finding this cause only when repeated and unsuccessful efforts force him to renounce all hope.

10. The form and specific gravity of the globules of bunt, which I had often examined under the microscope, the nature of which I had tried in various ways to change, which I could not help recognizing as organized bodies, and which I likened to globules of the rusts (*uredo*, de Cand.) and several other microscopic plants, made me suspect that they were the seeds, or, to speak more exactly, the *spores* of some cryptogam.

11. I had seen the globules of certain *uredos* that I kept in

water upon some leaves, to try to discover the manner in which they reproduce, put forth long stalks, which I shall describe elsewhere. On the 23rd of the Prairial of the year 12 (June, 1804) I attempted to suspend, in the bottom of a tumbler, the powder from three or four bunted kernels with a little water, which I added up to the height of one or two centimeters (one inch). I covered the glass, and left it in a quiet place. From time to time, with lenses of different strength, I examined a few drops of this water, in which there was always a rather large number of globules.

12. After three days, the decimal thermometer being held at a mean of 18° (14.2° R.), I found that several globules had put forth stalks, a small number of which bore an aigrette (Pl. 1, figs. 17–26) formed, apparently, of long, narrow leaves. Others showed only small buds (Pl. 1, fig. 3), which had just emarginated the integuments. Lastly, the majority still showed no change. But, continuing to observe in the same manner, one found each day a greater number of stalks, either simple (Pl. 1, fig. 4–9) or terminated by aigrettes, or by sorts of tufts, that is to say, by aigrettes the shoots of which were brought together and pressed, a little twisted and as if connected at the tip (Pl.1, fig. 27). The latter afterwards bear small oblong bodies that seem to be their fruits (Pl. 1, figs. 28–32). I have very often repeated this experiment, and it always has succeeded.

13. The grains or globules that make up the bunt dust are, therefore, the seeds (gemmae, gemmules, or spores) of a microscopic plant, and this same plant is the cause of the disease of the kernels.[1] But in order to place this truth in its full light I

[1] It had been thought that the bunted kernel was a kind of lycoperdon, an opinion that could not be sustained, and that, in the present state of our knowledge, its illustrious author probably would not offer. In the year 13 (1804), MM. Fourcroy and Vauquelin gave a chemical analysis of bunt, which had led them to regard this substance as a degeneration of the gluten of flour; but it was impossible that a chemical analysis alone, however perfect it might be, could lead to the discovery of the true cause of the disease. No special mention of bunt as a plant was made in the botanical part that follows the natural history of Buffon. M. de Candolle does not speak of it at all in the new edition of *Flore française*, although he cites the name as one of those given to *smut* or *blight*, which, as is known, is not the same disease. He, therefore, did not then regard bunt as a plant. It is true that later, towards the middle or the end of 1806, at about the time when I made known the detailed history of this cryptogam to the *Société de*

shall make known in detail this plant, its progress, and some conditions that influence the manner of its development.

III

Description of the Bunt Plant; Its Various Developments in Water and in Air

14. After the bunt[2] globules have remained from 60 to 72 hours in water or on some very moist substance that cannot maintain its growth, such as earth, paper, etc., the thermometer being held at a mean of 18° of the division in 100 parts (about 14.5° R.), one perceives upon some of them, on examining them under the microscope with a very strong lens, that the integument is slightly emarginated; then one notes, in transmitted light, a slightly elevated white point, which swells more and more (Pl. 1, fig. 3), and later lengthens, so that after five or six hours it takes the form of a small cylindrical stalk[3] (Pl. 1, figs. 4–7), the diameter of which sometimes reaches a half, sometimes only a third, and most often a quarter of that of the gemma.

15. I have said (7) that a part of these gemmae or globules stay at the surface of the water, and that the majority go to the bottom. I shall add that during growth some of the former sink, and that some of the others rise. Those that stay constantly at the bottom of the water, which are very numerous, often unite by a kind of gluten, exsert long, simple, slender stalks (Pl. 1, figs. 8 and 9), of which the part nearest the gemma is ordinarily so transparent that it is distinguished with difficulty, if the light be the least unfavorable. When it is like this, or when one observes it dry, this part of the stalk appears articulated, or, rather, composed of small cylindrical cells of its own diameter, and separated by transverse partitions more or less near together (Pl. 1, fig. 8). The other part is less transparent, and one is rarely able

Physique et d'Histoire naturelle de Genève, this learned scholar read at the Institute a memoir in which he says that bunt probably comes from the same origin as the rust and smut of wheat, the germs of which he thinks gain entrance through the roots with the nutrient juices of the plants.

[2] This should apply to bunt of the current year: the older the bunt, the more time it takes to germinate.

[3] The little bunt plant has no roots; its seeds, therefore, have no radicle, in which respect, among other things, it differs from the best known seeds.

to perceive cells in it. It does not grow as much as the former. It apparently is a sort of sheath or case, which originally envelops the whole stalk, and which the latter, by its extension, forces to become detached from the gemma.

16. The stalks that grow at the surface of the water, or that rise to the surface, are ordinarily larger. Scarcely have some of these acquired the length of one diameter of the gemma, when their tip appears black.[4] Soon this tip becomes granular (Pl. 1, figs. 12 and 13), and takes the form of a small star (Pl. 1, figs. 14 and 15), the rays of which, at first very short, later elongate like narrow leaves somewhat similar to those of certain liliaceae; so that the entire plant is not remotely unlike a young onion plant with its leaves and its bulb, especially when, after having begun its growth in the air, it sinks with its aigrette and finishes growing in the water (Pl. 1, figs. 22–25); or else it is extended in a stupose mass that seems to be composed of slender filaments, pressed against one another, terminated in a sharp end, a little distended in the middle, as if twisted and fastened near the tip (Pl. 1, fig. 27).

17. Let us distinguish, for greater clarity, the simple stalks (15), the liliaceous, and the tuft-like or stupose stalks (16). Let us distinguish in the first the sheath that bounds them, from the transparent part that is attached directly to the gemma; and in the others, the stalk, properly called, and the *leaves*, although, as will be seen later, I am far from regarding the shoots of the aigrettes as true leaves.

18. The leaves often arise quite near to the gemma, upon a very short stalk. Sometimes, on the contrary, this stalk is rather long, and one may then ordinarily perceive the elements or cells of which it is composed.

19. The young leaves are nearly always opaque, and consequently appear dark to transparent, especially when growth is vigorous.[5] In this case the liliaceous leaves are distorted, obtuse, and of a certain firmness. When the growth is weak, or when the

[4] *Black*, that is to say, *opaque*. In reflected light this part is white, as well as the little tuft of leaves that will be discussed, and that develops from it (Pl. 1, fig. 26).

[5] When the light reflected by the mirror under the object carrier is very strong, the leaves, which have grown out of the water, and are opaque only because of their tenuity, refract it like a prism, and appear to be colored.

star develops in the water after being formed at the surface, the leaves appear larger, more pointed, more flexible, and more transparent. They form, at first, a little pad upon the stalk. The simple shoots that grow at the bottom of the water (16) are ordinarily very flexible and elastic, usually a little undulated or tortuous. Sometimes they appear forked or provided with antler-like processes, but then they are thick and short (Pl. 1, figs. 10 and 11). Or else, without changing form and without leaving the water, they may acquire a length of as much as 45 or 50 times the diameter of the average gemma.

20. The three kinds of stalks seem disposed to assume a vertical direction; but they are often recumbent, because they fall down.

21. One, two, or three days after growth has begun, there are observed upon the leaves of the tuft-like stalks small, oblong, subcylindrical bodies, slightly recurved, lightly compressed, the length of which, double, triple, or quadruple the width, attains as much as twice the diameter of an ordinary gemma (Pl. 1, figs. 28–32). These small bodies are borne on a pedicel, often very short, sometimes rather long, and a little twisted. I have observed on some of them slight constrictions that seem to indicate the segments or partitions (Pl. 1, fig. 32). Sometimes, also, I have thought I saw them filled with little granules or extremely small globules; but these cases are very rare.

22. The majority of the liliaceous leaves fall after some time. Those of the stupose stalks expand (Pl. 1, figs. 33 and 34), and also sometimes fall. All become transparent; they are then very narrow; so that it appears that those still clinging to the stalk show a certain width or appear obtuse, and are composed of several leaves combined.

23. The expanded parts of the stupose stalks often acquire a considerable length, become serpentine or interlaced in a thousand ways, and sometimes become branched (Pl. 1, figs. 37 and 38). The fruit-like growths that occur on the same stupose stalk often remain attached when the latter develops, and change their relative position, like flowers or fruits on branches that continue to grow. All that is much better observed when, the gemma remaining in the water, the tip of the stalk or of the *leaves* is outside in very moist air. By degrees everything disappears, and

after a few months nothing remains but some granules or detached globules, sometimes quite distinct. I shall state below the precautions necessary to make this delicate observation clearly.

24. When the gemmae have remained in the water for one or two days, and when, consequently, they have become a little more transparent, the clearest area observed in transmitted light is towards the most elevated part of the hemisphere observable; which proves that the opacity comes from the integument rather than the interior of the globule.

25. The middle of the gemmae that have produced stalks of a certain length appears flattened or even concave, translucent, of a reddish-yellow tint, as if metallic. A sort of rose engine pattern [the reticulations] of a certain regularity is observed. These gemmae are evidently empty; and as the envelope peripherally presents to the eye a greater thickness in perspective, one might think them surrounded by an opaque pad (Pl. 1, figs. 32 and 36).

26. Sometimes, after a very prolonged stay in water, the exterior integument, which is of the rose engine pattern and colored, ruptures and becomes detached by fragments. It then leaves exposed an empty, colorless, transparent globule. The latter originally contained the embryo of the stalk, which was itself enveloped, as we have seen, by a sort of case or sheath: thus this embryo is at first under three integuments or envelopes.

27. Before germination, the gemma can be forced to discharge its contents by pressing it lightly in a drop of water between two flat glasses. It presents then precisely the same appearance as when it has exserted a long stalk. There emerge from it several very irregular globules, or shapeless masses, some of which are so small as to be seen with difficulty under the strongest lenses. These globules or molecules, therefore, constitute in the gemma the embryo of the stalk. This embryo is difficult to see in bunt; but I shall give the history of the embryo of a plant of the same family, whose embryo, which is perfectly made out in the gemma, diminishes in proportion as the stalk grows, and finally disappears entirely when the latter has acquired a certain length.

28. The granules of §23 probably would become gemmae similar to those from which they originate, if they were suitably placed, that is to say, in the embryo of the seed of some young

head of wheat. Of this the following observations scarcely admit any doubt.

IV

Appearance and Progress of Bunt in the Embryo of the Kernel

29. Towards the middle of May, bunt can be recognized in the fields due to be infected by it; but it must not be sought in the heads then emerging: those that harbor it are, on the contrary, still enveloped by leaves, and are on the shortest stalks.

30. The bunted wheat plants also are those whose leaves are most laden with that yellow crust, commonly called *rust*, a species of *uredo* of de Candolle.

I do not maintain, however, that rust and bunt always occur together; I say only that, when the wheat is attacked by these two diseases at the same time, the bunted plants also are those whose leaves are the most heavily laden with rust.

31. This crust appears, at least very noticeably, only on the most fully developed leaves; and, consequently, the leaf whose base still envelops the head, and may be regarded as the *terminal one*, also is the last on which this parasitic growth appears.

32. Now, in general, the bunted heads are found under the base of a *terminal leaf* which is already more or less laden with rust, although there is little or none of it on the terminal leaves of other culms of the same height or whose heads have attained the same degree of maturity.

33. The embryo of the bunted head bears anthers of a more yellowish green than those of healthy, no more advanced heads; the lobes of these anthers are deformed, contorted, and turned downward at the bottom like an arrowhead; the stigmas are more or less disposed to expand; the pistil, which is larger, is of a dark green, or bears externally a patch of this color (Pl. 2, figs. 1–9); crushed between the fingers, it has a bad odor, and it is filled with a greenish gray or white paste mottled with green.

34. If one takes a little of this paste with the point of a needle, and places it on the object carrier in a drop of clear water, he observes a great number of globules of different sizes, from the smallest that can be seen with the strongest lenses to globules as large as the gemmae of mature bunt (Pl. 2, figs. 11–21).

35. The most advanced heads are those in which the largest globules are the most numerous, and reciprocally; so that one finds only the medium or small ones in the very young embryos; but they perfectly resemble those of the same size from the most advanced heads. I have seen such globules in heads that were only 22 to 23 millimeters (10 lines) in length, not to speak of those about which there can be any doubt.

36. These globules are certainly the bunt gemmae in a state of imperfect maturity; for, aside from the fact that their like is not found in healthy wheat,[6] the most advanced germinate in water, producing stalks like these gemmae do; only it takes them longer, all other things being equal; and the eye can travel from the largest of these globules to the smallest by absolutely imperceptible gradations.

37. Some, generally the largest, seem to have grown like small sessile fungi on shapeless fragments of a firm material (Pl. 2, figs. 19 and 20); others on a sort of delicate, transparent spawn, which dilates in water, like a sponge, and is encountered again in the water-suspended dust of the fully mature bunt. Finally, some smaller ones appear to be attached in clusters (Pl. 2, fig. 14).

38. As to the minute description of these globules, I shall say that they have the remarkable transparency and clearness of *pure water;* that in general, excepting the largest, they are rather spherical, save for the flatness due to the excess of their specific gravity over that of water; that some appear empty or filled with a homogeneous translucent substance; that others seem to contain one or several secondary globules of very variable sizes.

39. The largest of these secondary globules, real or apparent, are in the interior; but the smallest, assembled in piles, occupy the surface. They are portions of the outer integument, which is beginning to form (25). These differences of position become evident when gemmae, not yet very mature, are rolled over in a drop of water.

40. One notices in the embryo of the seed of healthy wheat and in this seed itself, as it approaches maturity, several other

[6] An exception must be made of the smallest, which cannot be distinguished from those found not only in the embryo of the seed of healthy wheat, but also in nearly all parts of other plants.

kinds of globules, which it is very easy to distinguish from those we have just described (the smallest excepted). One kind are flattened (Pl. 3, fig. 1), and refract the light, so that they sometimes appear to be blue or very light green. They are more uniform than those of immature bunt, and the volume of the largest does not equal that of an average gemma of the latter. Other globules, seen in very large numbers in wheat that is still in the milk, have, in transmitted light, the appearance of mother-of-pearl. They are very irregular, and larger in general than those of bunt. They are perhaps only drops of a liquid that is immiscible with that in which they float. Neither kind contains secondary globules. The globules of pollen sometimes accidentally become detached from the anthers long before they are mature, and become mixed with the others. They are large, nearly uniform, compressed, often heaped up like piles of coins. The interior of the embryo seems sometimes, by transmitted light, to be filled with globules, but this is ordinarily only an appearance, and these fictitious globules do not become detached.

Now that it is well proved that bunt is a plant, the spores of which germinate in the open air and can be detected long before their maturity in the wheat embryo, it remains for us to investigate how they gain entry. This is the purpose of the following section.

V

Studies on the Introduction of the Bunt Plant into That of Wheat. Experiments and Observations Relative to This Subject

41. One means of finding how the bunt plant enters the wheat plant is, it seems, to observe it with care throughout all the stages of development that it is capable of exhibiting.

I said in §23 that I would return to the observation there described, and that I would indicate the means of making it with clarity. The manner in which I procured the first bunt plants that I observed has been seen in §11. There are a few additional precautions to be taken when one proposes to follow them for a very long time.

a. Instead of suspending at one time the dust from two or three bunted kernels of wheat, one makes a suspension of that

from only one, and at the same time removes the shreds of epidermis or bran, from which the dust falls away, the stamens, etc., which are easily seen.

The glass is about three-fourths filled with distilled water, and allowed to settle for eight or ten minutes.

Most of this water is decanted, leaving only as much as is necessary to prevent losing the bunt that is at the bottom.

It is stirred, the glass is filled anew, and when the bunt has settled, it is emptied as the first time; it is filled again, is covered to protect it completely from dust, without, however, hermetically sealing it, and allowed to stand.

b. It is necessary to use very pure and recently distilled water, so that it may not have been long exposed to the open air, from which are always deposited dust, spores of moulds, or other microscopic plants, which grow there and interfere with the experiment. This precaution is further necessary to prevent the development of a large number of monads and other animalcules, which, in their movements, break the most delicate parts of the little plant that we are about to observe.

c. The gemmae of bunt begin to put forth stalks

$2\frac{1}{2}$ or 3 days after immersion at a mean temperature of		17 or	18° C.
3	4	14	15
5	6	11	12
9	10	7	8
11	12	4	5

d. At about the time when, according to the temperature, it is supposed that growth has begun, one takes from the surface of the water of the first glass a little of a sort of pellicule with which that surface appears to the naked eye to be lightly veiled, and puts it into a drop of very pure water on the object carrier.

e. At this stage, the stalks of the three forms (17) are ordinarily little advanced, and one still sees a few gemmae that seem to have undergone no change. Within a day or two, several tests are made that may be observed without other precautions. But when the growth is more advanced, and when the fruit-like growths (12 and 21) appear well formed upon a few stupose stalks, the drop is covered with a concave glass, which should not touch it, but which, however, should be sufficiently thin and low to permit it to serve as a strong lens.

f. In order to prevent the concave glass from being dimmed on the lower surface by the evaporation of the water, its temperature and that of the lens carrier are kept a little higher than that of the object carrier during the operation.

It is simpler and more convenient to observe without the cover when there is no likelihood of dust. Thus the drop is covered only after each observation.

g. The object carrier is next placed on a lightly compressed cushion of wet rags, which rests on a flat body, impermeable to water. It is all covered with a bell glass or a goblet.

h. The humidity under the bell glass is easily maintained, even at a temperature of 25 to 26° C. (about 20° R.), by moistening the little cushion once or twice a day. In this way, there is need of replacing the water in the drop under observation only once every 24 hours, even supposing it to be very small. Thus, uncovering it too often is avoided.

i. It can further be preserved intact for whole months without adding water to it by placing the object carrier, covered by a watch glass, in a screw-capped tin box half full of wet paper or rags, which is filled to the top with slightly moistened paper. In this way it is possible to transport this box wherever desired, provided the drop be very small, without the latter being deranged, and without running the risk of its becoming desiccated.[7]

42. By following the observations for a sufficient time, then, it is very clearly seen that the tufts of the stupose stalks dilate and spread out, and that their leaves extend considerably in length. These leaves behave in their development like the naked stalks (15 and 17). The part next to the gemma or the principal stalk is much the most transparent: in it are distinguished some sort of elements or cells, the transverse walls of which take the form of granules, which at times become rather distinct globules (§23). The same thing happens to the filaments of the aigrettes (Pl. 1, fig. 35); however, these latter do not elongate so much,

[7] These details may appear to be minute, but I have thought them necessary in order to avert precipitate judgments concerning the experimental results, which are delicate and difficult to obtain in a very clear manner. Moreover, they are applicable not only to bunt, but to a very large number of microscopic plants that they provide the means of observing more easily.

and sometimes the blades or little leaves, of which they appear to be composed, are transformed, without noticeable extension, into a continuous train of globules of a diameter that slightly surpasses the width of the leaf. This sort of development is very rare; but we shall see (sec. VI.) that it has a marked analogy to the fructification of several other internal plants.

The parts of the aigrettes often are detached, and are not prevented thereby from producing granules or globules.

43. It is easy to prove now that *the bunt plant begins its growth on the wheat plant, or in its vicinity, and not within it.*

For (1) I have observed on young wheat plants started in soil in which I had mixed a great deal of bunt, and had kept very moist, several aigrettes and several stupose stalks, some of which bore their fruits, or growths that resembled them; and (2) one cannot imagine that the mature gemmae of bunt enter the wheat plant; for, although they are very small when compared to the seeds of the best known plants, they are, nevertheless, still far too large to be admitted into the openings this plant can offer them.

44. It is, moreover, easy to prove that *the stalks, the branches, or some of the growths of bunt penetrate in one way or another into the wheat plant while the latter is still very young; that they arrive at the seat of the embryo of the seed, where they produce globules that enlarge with the* [*wheat*] *head, and finally become for the most part perfect gemmae when the wheat approaches maturity.*

For, first, the bunt gemmae can begin growth only in the open (23); and, second, we have seen in paragraphs 34, 35, and 36 that gemmae of all sizes, from those that appear as very small granules or globules to those that have acquired their maximal volume, are encountered in very great numbers in the embryo of the kernel, in heads still very far from emerging from their coverings: therefore, *these very small globules or the plant that bears them, that is to say, the stalks that the gemma produces outside, or some of its branches, passed into the embryo of the seed, while the wheat plant was still very young.*

45. That these little globules, which are nothing but very immature bunt gemmae are produced outside and then become scattered; that, disseminated by chance, a small part enter the plant through the roots; and that, circulating with the fluids,

the small number of them that reach the embryo enlarge and mature there: one feels, withal, how improbable such a supposition is, and it will later be seen that it is in little accord with experience.

46. Thus, although I have never been able by direct experiments to assure myself of the existence within the wheat plant of the ultimate ramifications of that of bunt, doubtless because of their excessive tenuity, which permits them to be perceived only upon a very clear glass, it is, nevertheless, most probable that these ramifications penetrate into this plant, and insinuate themselves into the embryo, where they fructify, and where the seeds mature.

47. We have seen that at the bottom of the water the bunt gemmae produce only naked, somewhat etiolated stalks, and that the aigrettes and the stupose stalks, which are beyond a doubt the result of a more vigorous growth, arise only from gemmae that germinate at the surface of the water or on moist bodies. Moreover, it can be proved by direct experiments that these latter developments can take place only in the open air,[8] and that otherwise there are produced only deformed stalks, which do not grow, or etiolated stalks. Thus, it can be only the gemmae that are at the surface of the soil, or very near the surface, that serve to propagate bunt.

48. This plant is exceedingly fragile and delicate; it would quickly be destroyed by rain, wind, and other incidents, from which it can escape only by the protection of the wheat plant, into which it is consequently necessary that it penetrate early. The gemmae, moistened by dew, germinate on this plant even

[8] This need of air, which appears at this stage, relatively to the volume of the plant, much more imperative than for the majority of other plants, diminishes considerably, if, indeed, it does not become absolutely *nil*, at the time of further developments, which probably should in the natural state take place in the interior of another plant, where the air penetrates only indirectly. If in a tumbler, simply covered with paper, in which the bunt is beginning to produce aigrettes and stupose stalks at the surface of the water, one takes some of these stalks, with gemmae beginning to germinate and others not yet germinating, when he puts them in a drop of water upon the object carrier, and covers them tightly with a concave glass, he will find, after a few days, that only the stupose stalks and the aigrettes already formed have continued to develop, whereas the rest have remained in very nearly the same stage, although the temperature was sufficient for the development of all or nearly all of those in the glass at the surface of the water.

when it is beginning to come up, or on moist soil, some days after the germination of the more deeply buried wheat; and when it emerges, the aigrettes are formed, and the stupose stalks are about ready to expand. It is then probably the shoots of the aigrettes, or those of the stupose stalks, that are destined to enter the wheat plant.

49. The dew, it is true, often dissipates during the day, but the bunt is not prevented from developing, by having several times been successively moistened and dried, provided, however, that this does not occur at a very high temperature, or too near the time when growth begins.

50. The bunt plant, under natural conditions, usually is destroyed after a few days; yet the branches that have penetrated the wheat plant keep growing: thus, in our observations on a small scale, we see the ultimate ramifications of the plant continue to grow, though the gemma be empty, or even when it is entirely destroyed. Moreover, the best known plants offer many analogous cases.

51. As to fructification, its abundance in the bunted kernel hinders observing there the arrangement of the gemmae. We shall soon see what analogy permits to conjecture in this regard, according to what happens in the case of some other internal plants whose history I shall sketch.

52. Meanwhile there follows in summary that of bunt:

From a gemma, which one may consider as a fragment of the plant, and of which the exterior coat, which is brown or yellow and vermiculate, cracks and is parted after a long sojourn in water and exposes another, transparent and colorless, arises a stalk, at first enclosed in a sort of sheath or case, which it soon pierces, producing at its extremity a pad composed of small opaque grains, each of which becomes a stalk similar to the first, enclosed as it is in a sheath, but a smaller one. This latter stalk sometimes branches, from which one may presume that each of these secondary stalks, in favorable circumstances, might produce (as I have sometimes seen, though in fact very rarely), as well as the mother stalk, a pad composed of granules, each of which would become a ternary stalk, etc.

53. Thus this plant is a true vegetable hydra, comparable to the hydras or polyps of Trembley; and what renders the re-

semblance as complete as it can be from one kingdom to the other is that each stalk, the principal one as well as the secondary and ternary ones, is composed of elements or parts that, becoming separated, mature, and probably form anew gemmae entirely like those whence they originate, etc.; in the same way as each grain or each perceptible fragment of the animal hydra is capable of reproducing a polyp exactly like the mother polyp.

54. In fact, several principal stalks that I have called naked, push their sheath ahead without piercing it, and elongate without branching; but this difference is only accidental, and depends upon their having continually grown under water: it is a kind of etiolation, comparable to that produced by deficient light in the case of other plants; and such a naked stalk would have assumed one of the two other forms, had circumstances been different.

55. As to the development of the aigrettes, it is nearly the same as that of the stupose stalks, with the difference that the latter are more extended, and, what is very noticeable, that they nearly always bear growths that have the appearance of small fruits, while one very rarely sees any of them on the others. Nevertheless, it is possible that these differences may not be other than accidental; it is at least certain that when the newly formed liliaceous stalks are immersed in water, or laid on its surface, they develop a little differently. (See the figures and their explanation.)

56. But, since it appears that the ultimate ramifications of the plant or, to speak more exactly, the whole plant, forms its fruits or gemmae, which, in a way, are only parts of it, the question arises as to what are the growths that the stupose stalks bear, and of what use are they?

Would they really be fruits? But they would be too large to be capable of penetrating *en masse* into the wheat plant, and they would not be abundant enough for the granules, which can sometimes be observed in them, to be able, in passing into this plant, to form the fructification of bunt, unless these fruits are very highly regenerative, like those of several other plants, or like the *eggs* of certain polyps, each fragment of which is equally capable of reproducing a new polyp.

As these little bodies are quite similar to anthers or even cat-

kins, and are scarcely ever found except on stalks a little different from the others, I have thought that they might be male organs, which would sufficiently explain why these stalks grow more than the aigrettes.

These growths might be parasites of bunt, or in a way, parasites of the second order.

There will be found, in the following section, the history of several growths of the same form, or nearly so, which seem to have some analogy to these, that may throw some light upon their nature.

57. I have said (48) that the bunt plant must early penetrate the wheat plant, in consequence of its delicate nature and of the necessity that it begin its growth in the open air (47). Moreover, I prove it by direct experiments:

(1) I scattered bunt, either mixed in some pulverized earth or suspended in water, upon wheat plants of different ages, from the time when they had emerged from the soil only three or four centimeters to that when the majority of the leaves had developed. I multiplied these experiments, and I made them upon large enough quantities of wheat for their results to be decisive: they did not yield more bunt than the average taken with much care in the same field, where, in general, there was very little.

(2) At the time when the heads began to appear, and in a field where some of them were bunted, I noted about 50 that were not, but the plants of which appeared to have the characters of those that should bear that kind; however, none became bunted.

(3) At the same period, and in the same field, I threshed with some of the bunt of that year several hundred heads taken at random, of which only one later was bunted.

(4) In one experiment in which bunt was scattered upon the soil immediately, or very soon after the wheat was sowed, there were many bunted heads.

Thus, *it is only at the time of germination, or a very little while after, that the introduction of the bunt plant into that of the wheat occurs.*

58. After all that precedes, there can be no doubt that the bunt plant is destined to pass a part of its life in the wheat plant, and to fructify in the kernel. It may be regarded then as an internal plant, and be compared in this regard to the internal

worms of animals. The number of species of internal plants should be much greater than of other plants; at least it has appeared to me until the present that each of the latter is subject to attack by several of the former, and that the internal plant that attacks one species is not adapted to attacking another.

VI

Some Other Internal Plants Whose History May Serve to Throw Some Light on the Fructification of Bunt

The Uredo or Rust of Wheat

59. On the upper surface of wheat leaves, as early as the month of April, there are found, as is well known, small, yellow, oblong or linear tubercles, which, becoming constantly more numerous, often end by uniting, and by entirely encrusting the leaf. They also are found, but very rarely, on the under surface. Sometimes to a yellow tubercle on one surface, there is a corresponding blackish one on the other, containing some of the little club-shape bodies called *puccinias*, of which I shall soon speak. In this country the effects of this disease, known under the name of *rust* (*uredo lineaire*, de Cand.), are ordinarily confined to this: it does not seem to have any influence on the seed.

These tubercles are formed by the swollen epidermis. They receive their color from the powder with which they are filled. This dust, which is scattered abroad when they burst, appears under the microscope to consist of globules larger in general than those of bunt, some of them having double the diameter. After 40 or 50 hours in water, at a temperature of 20 to 25° C. (16 to 20° R.), they put out large, long, jointed stalks, but on none of them have I yet seen either aigrettes or stupose stalks.

60. In the month of July, I found, on the leaves and chiefly on the culms of a wheat plant from seed I had sown in March and April, a rust that might be of a different species from that of which I have just spoken. I believe it is this late rust of which Sir Joseph Banks has given a description, which I know only from a few words reported in *Bibliothèque britannique*, and from what I have been able to gather from the conversation of a naturalist scholar who has read the memoir. M. de Candolle, in the

new edition of *Flore française* has sketched, in part, the history of its fructification, under the name of *puccinie des graminées.*

I had observed it for a long time on wheat culms, the seed of which, purposely infected at the ordinary time of harvest, had yielded heads for the most part bunted; but I had not recognized it as a rust.

It was manifest only as short, velvety streaks filled with puccinias. I have since found some globules among the puccinias in similar spots, which affected the plant only very slightly.

61. But the epidermis of the leaves and stems of wheat sown in March and April was raised or torn in a thousand places by tubercles of very irregular length, and of a half millimeter in width. Some of them were black, others the color of iron rust. The first form a rather hard sort of crust; the others are covered with a dust, under which is again found the black crust, or a black spot,which the cracked or split epidermis partly covers.

62. These tubercles are filled with puccinias or with slightly compressed oval spheroids, different from those of the preceding rust, which are spherical. Sometimes the puccinias and the spheroids are together in the same tubercle; sometimes it is filled with only one or the other. The former ordinarily are found in the black tubercles; the spheroids form the rust-colored dust.

63. The shape of the puccinias varies much according to age or circumstance. The youngest or the smallest comprise a colorless, transparent, oblong mass; a little more advanced, they are less transparent, as if embroidered on the surface, and borne on a kind of stalk or pedicel, which often is flattened, transparent, and in general of the same length as themselves. Others bear a larger or longer body, formed of a cylindrical sheath or pericarp, terminated in a blunt point, enclosing one or two spheroids, rarely three; one of which, the least distinct, is borne on the pedicel, and the other, above this one, is better formed but nearly always a little oval or elongated in the direction of the axis of the sheath.

64. These spheroids, in enlarging, distend the walls of the pericarp, which then appears constricted about the middle, or it forms there a circular section, at first very narrow, which continually enlarges, so that the upper spheroid appears to be coifed with a sort of cap and lodged in a cup formed by the lower part

of the pericarp that encloses the other spheroid, and extends beyond it more or less.

65. The upper spheroid is finally detached from the rest of the spindle, and the same thing happens, but later, to the lower spheroid. The latter often aborts, and the part of the pericarp containing its embryo remains empty. A sort of appendage or stem is sometimes seen attached to the upper globule, which the latter often retains when it is detached. This stem, which resembles the pedicel of the spindle, might give the impression that the globule was beginning to become spindle-shape; in fact, it differs little then from less advanced puccinias or from those with only one locule: but the details into which I have just entered, and those that will follow, prove clearly that there is nothing in this, and that the growth of this plant follows a course contrary to that which one would assume to be necessary. This appendage is probably only débris from the aborted spheroid, or some remains of a coat common to the two spheroids.

I did not follow these different developments of one individual puccinia, which would have been very difficult, since they operate only on the living plant attacked; but several times I did observe all their gradations in a large number of individuals that I had under observation at the same time.

66. Some of these spheroids, or globules thus detached, are partly transparent. A small opaque ball, granular and very distinct from the rest of the globule, is then seen in the middle. This, after being for a few hours in water at a sufficiently high temperature, and after having pierced the oval spheroid perpendicularly to the long axis, develops into a stalk that ordinarily is distorted like the tendril of the vine.

67. This stalk, sometimes falling and flattening out on the object carrier, assumes a branching form, or appears to be provided with antler-like structures; which is often only the effect of the spirals of the helix, which lie upon one another. But it also happens sometimes that the stalks are really branched, and resemble trees stripped of their leaves and small branches.

68. The puccinias in the black spots often are found aggregated in balls of 100 or 150 on a rounded mass where they appear to be rooted by their pedicels, with their apices outside, so

that the whole grossly resembles a head of globe thistle (*sphaerocephalus* or *retro*).

69. It is rare that this arrangement is naturally presented to the observer; but it can be provided. To accomplish this, one lifts a very small scale from a black tubercle with a penknife, places it in a drop of water on a flat glass, and lays another glass on it, pressing a little. Then the little black mass, which at first appeared confused, divides into distinct parts such as we have just described. Upon some of them, puccinias of all ages are seen; and the youngest are also sometimes found ranged parallel on an elongated placenta, like the pips of the pumpkin or melon on the flesh of these fruits.

70. Here, then, in a few words, is the history of this internal plant: the gemmae put out a stalk that enters that of the wheat plant, probably during germination, or shortly after. It produces under the epidermis, or near the epidermis, umbel-like structures composed of puccinias, still extremely young, which appear to be nothing other than the tips of the stalks of an aigrette, whose pedicels are united at the base in a spherical head or receptacle. These young puccinias become little by little club- or spindle-shape pericarps of two locules, each enclosing a globule (gemma or spore). Sometimes there is only one locule; sometimes, but rarely, there are three or even four. These globules become detached as they mature. Their accumulation forces the epidermis to rupture in order to free them, and the rest of the spindles mature or become desiccated, accordingly as they are more or less advanced, or more or less exposed, in forming black spots on the stalk. In favorable circumstances, the globules, in their turn, put out stalks similar to those from which they arose, etc.

71. I have not read Sir Joseph Banks' memoir; but, judging from what I have heard of it, its illustrious author thinks that the globules of the rust are the first stage in the life of the plant, and the puccinias or spindle-shape bodies the second. If the observations I have just reported are exact, it cannot be doubted that the globules are a growth posterior to that of the spindles.[9] These latter, however, would not then be the first stage of the

[9] Sometimes the puccinias take the form of a spindle.

plant; for the first is that of the stalk that emerges from the globules: but they should be the first stage of its fructification.

It is true that the puccinias[10] in general appear outside only after the globules, and that thus they appear to be the second stage of the plant; but this is only an appearance, and the globules were, none the less, originally enclosed in the puccinias.

The Uredos of Couch-grass, Asparagus, and Garlic

72. One finds on the leaves of couch-grass an uredo, whose pulverulent tubercles are a reddish brown, the globules spherical, and the pericarps, smaller than those of the preceding uredo, generally more distinct of pedicel. The one kind are slender and terminated by a cylindrical or conical appendage; the others are large, short, and, for the most part, rounded or globular at the tip, doubtless because the upper part of the coat has fallen away.

73. The uredo of asparagus attacks alike the stems, the leaves, and the fruits. One finds beneath the epidermis, in inconspicuous tubercles, a clear brown dust that becomes detached when the tubercle opens, and exposes the puccinias. This dust, unaided, scarcely ever appears outside, and it is necessary to raise the epidermis to find it. It is composed of spherical globules. The puccinias are larger than those of couch-grass. Moreover, these two internal plants resemble each other more than the uredo of couch-grass resembles that of wheat (60–71); which is quite remarkable, in view of the differences of the genera.

74. I found on the leaves of garlic an uredo, whose globules produce in water, in a short time, stalks that resemble hartshorns, and that become very long. In general the tubercles are yellow: more rarely black ones are found, formed of puccinias with two locules, larger than those of wheat, but whose history, however, is nearly the same. They are also of very various shapes, and the lower globule often blights.

The Uredos of Bean, Sorrel, and Darnel

75. The puccinias of the uredo of bean, and those of the bilateral uredo of de Candolle, which I have found on common sorrel, have only one locule, and differ from the globules only

[10] I mean here by *puccinia* the pericarp with its pedicel, and I nearly always use this word in the same sense.

because they are pedicellate, and because those of the bean are a little pear-shape. When the latter are very young, they resemble Prince Rupert's drops, the terminal portion of which, instead of being a continuous curve, might be slightly angular.

76. The history of six internal plants that we have just described is, moreover, nearly the same as that of the uredo of wheat.

The Uredo of Rose and That of Currant

77. In the first memoir on bunt that I read to the Society of Montauban, I was inclined to think that the puccinias of the rose were the male organs of the uredo among which they are found. I am now convinced that they are pericarps, and that it is from similar pericarps, but much less advanced, that the globules of this uredo come. One finds, in fact, on removing the orange-color dust from a tubercle, that the substance of the leaf immediately below, viewed under the microscope, and lightly compressed between two flat glasses in a little water, is divided in small, rounded heaps, composed of curved transparent tubes, the youngest of which are nearly colorless. They later become reddish yellow, and swell towards the tip. Small, sparse, irregular grains are seen there. Soon these small tubes become erect; the internal grains appear more distinct, better ordered; the swollen part continually draws nearer to the form of the cylindrical top of the mature puccinia; but it is still transparent, and within may sometimes be seen very distinctly as many as a dozen globules ranged in file, one after another, and of nearly the same color as the mature globules. The puccinias take on color, rise, and become more and more opaque, until finally the pericarp is completely black, and in the condition in which it is seen externally.

78. The uredo of the common currant (*ribes rubrum* L.) much resembles that of the rose, and behaves nearly the same. The tip of the pericarps is rounded; the layers are better marked, there being only three or four of them. Several puccinias, some time after beginning to form, take the shape of a Prince Rupert's drop; others are curved in a semicircle, like those of the rose; but here one notices, in addition, one or two swellings, besides that of the tip. In the more advanced ones, those about to take the form they should retain, one observes only four or five globules

that are most often perfectly distinct, although smaller than those that are detached or become detached. A few puccinias also are seen here with a single locule, or pedicellate globules similar to those sometimes encountered in the wheat rust (65).

Reflections on the Internal Plants Whose History We Have Just Sketched

79. It does not suffice for the globules enclosed by the puccinias that are dried in the air, as it does for those that they emit under the epidermis before their coat is hardened, to remain a few hours in water, in order to produce stalks. There also are detached globules that do not germinate at all or germinate with difficulty; and it may be conjectured with much probability that they have come from too far advanced puccinias. One finds them, in fact, principally in the black tubercles with the dry puccinias.

80. A question, therefore, here arises that we shall discuss before going farther.

Of what use are the puccinias that come to maturity in the open air, and occur sometimes in very large proportion among the uredos?

To answer this plausibly, if not wholly satisfactorily, it is necessary to enter into some preliminary details.

81. Since the gemmae of the uredos put out stalks, and as their fructifications are found under the epidermis of the plants they have attacked, and their progress can be followed from their origin to the time when new gemmae are reproduced and detached, it cannot be doubted that these stalks penetrate into the young plant, or, if it is a tree, into its young shoots, while their delicacy permits.

82. But the gemmae of the uredo of the rose, which I shall take here as an example, being scattered upon the ground or upon the branches in the autumn or at the end of the summer, or falling with the dried leaf, are unable to delay germination, and consequently their plant should be destroyed quite a long time before it will be able to penetrate into the young buds, which appear only in the following spring: How then will the reproduction of the parasitic plant take place?

This new question is bound up with the first, the solution of which it presents along with its own.

83. The backward gemmae and the puccinias probably supply it. For some of the latter, without doubt, a considerable time is necessary for the emission of the globules that they contain, and for these globules later to germinate. It is quite possible that a few months do not suffice for certain of these, but that one or more years are necessary.[11] This will be confirmed, I think, by some experiments I have attempted on this subject.

84. The globules or gemmae that require only a few hours for germination are not for that reason without use; they serve for the reproduction of the uredo in the plants whose young shoots are renewed or succeed each other several times in the same season.

85. Besides, it is quite possible that the uredo, once introduced into the trunk or the branches of the tree, lives there until the death of the latter, always ready to fructify under the epidermis of the leaves, the stems, or the fruit; that it is fixed here, in a way, like the tree is in the ground by its roots.

86. The uredos with black dust, which have been called *smut* or *blight,* present some phenomena analogous to those of bunt and the uredos with yellow, orange, or brown dust. They are certainly internal plants. The one that attacks wheat does not renew itself at all in the same season, as Bulliard appears to have thought. The dust of this uredo is composed of gemmae for the most part much smaller than those of bunt and of the rusts. In water they put out naked and simple stalks, though rarely double or triple ones; at other times the gemmae that float at the surface of the water produce there aigrettes or series of globules; but all these are much smaller and, consequently, still more difficult to observe than in the case of bunt or the rusts.

87. One finds the blight or smut of wheat in much younger heads, or those much farther from maturity than the heads that bear bunt. One of them viewed through a magnifying glass and

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[11] It is thus that the butterfly of the liveried caterpillar (and without doubt several others) in summer lays eggs that, as I have observed it, do not hatch until the following spring, at a temperature much lower than that they then experience; because they are covered by a varnish that retards the evaporation of the humours and can be dissolved only by the winter rains.

under the microscope is represented in Pl. 3, figs. 6 and 7. The interior is filled at this stage with little rounded groups (Pl. 3, fig. 8), which I at first took for heaps of gemmae, but which are very probably composed of puccinias with a single locule, analogous to those of the sorrel.

88. As these puccinias are very small, it is difficult to distinguish them from true gemmae; and it is because of this that one often thinks he has found some of the latter that do not germinate, or that germinate only with difficulty, whereas in the same species others require only three or four hours for germination.

89. These puccinias or backward gemmae are necessary to several of these uredos. Often carried in the air before the maturity of the seeds of the species that they attack, they are unable to attach themselves to them, and only rarely find themselves in position to penetrate into their seedlings when they themselves germinate. The seeds must, therefore, be capable of living for a greater or less period upon the ground without producing stalks, in order that some of them may always germinate at the time of germination of the [host] plants in which their fructification should take place.

90. Although I have yet to speak of certain uredineous growths, since they present peculiarities, some of which may cast doubt upon their vegetable nature, I shall stop yet a moment to consider the similarities of bunt to the uredos that we have just described, especially those that relate to their fructifications.

91. Everything leads to the belief that the fructification in bunt is entirely analogous to that of the uredos; since the tips of the stalks or of the aigrettes which have penetrated as far as the seed become filled with globules which enlarge and pass out of them, but they are so abundant and therefore so compressed and their coats are so delicate that they cannot be distinguished there.

92. As to the mature puccinias, they would become useless; for, (1) the bunted kernels correspond to them, as we shall see; (2) the gemmae of bunt, in general, require much more time to germinate than those of the uredos; and (3) bunt becomes attached to the kernels, especially to those that bear a small tuft on the end opposite the germ, which so orients its stalk as to penetrate the wheat plant when it germinates.

93. Since bunt attacks the entire mass of the kernel, one might think that there is more difference than really exists between it and the black- or brown-dust uredos, which scarcely attack more than the epidermis of the plants.

But, in addition to the uredos' often attacking the entire thickness of the leaves, like *bifrons*, and their globules and puccinias sometimes being found in the stem itself, one quite often sees heads of wheat formed of very elongated empty pistils or ovaries (Pl. 3, figs. 3 and 4), some of which are lined internally with confluent tubercles filled with bunt. This proves that bunt develops on the inner walls of the pistil, as the rust of wheat develops on the chaff or *glumes*, which have been regarded as petals, and that they accumulate there to the point of filling the seed, and excluding the flour from it.

Some Uredos or Uredineous Growths with White Dust

94. *a.* On the under surface of leaves of mountain spinach (*atriplex patula* L.) may sometimes be seen very unequal and irregular, whitish or yellowish spots, which appear to be a little hollow and sometimes resemble arborizations. The yellow tint penetrates the whole leaf, and the corresponding places on the other side are slightly raised in humps. They bear somewhat cottony or velvety, gray tubercles, speckled with very small black points.

b. Under the microscope the cottony tubercles resemble copses of dichotomous shrubs, bearing at the tip of each of the ultimate branches globules of various sizes, the smallest of which are transparent.

c. These shrubs are fistular, extremely sensitive to the influences of humidity or of dryness; so that, if one blows a little moist breath on the leaf in which they are implanted, they each make two or three turns upon themselves, instantly turning again to resume their original status. The trunks of some of them appeared to me to be formed by a sort of ribbon rolled in a hollow cylinder like a twisted cannon.

d. When they are detached, and moistened in the same manner, they become filled with water while being twisted, and release it an instant later through the base of their trunk, carrying with it a few very small particles of a substance, whose nature it would not be easy to determine.

e. However slightly apparent the yellow spot is on the upper surface of the leaf, some of these little shrub-like structures are nearly always found on the corresponding points of the under surface; sometimes also they occur as isolated and scattered gemmae that, moreover, do not appear to have been brought there; at other times, finally, the place corresponding to the yellow spot appears to differ from the rest of the surface only by the color, which is always a little less perceptible than on the other side.

f. The globules fall when their size nearly equals that of a gemma of bunt. They are ovoid and slightly transparent. After a few hours in water at a slightly raised temperature, they put out dichotomous stalks that nevertheless differ from those from which their seed originate, probably because of the difference in the media in which they have grown.

g. The opacity of the globules lessens in proportion as the stalk grows, and they become absolutely transparent; so that it cannot be doubted that they originally contained the embryo of this same stalk. As we have seen, a similar thing happens, in a more or less marked manner, to the gemmae of bunt and uredos.

h. I have found this plant upon *chenopodium vulvaria* L. and lettuce. The latter is a little different. The spots it produces upon the leaf have a violet tint. The shrub-like structures are larger; in some of them the trunk is divided first into three branches instead of two, each of which then subdivides into three others, etc. Their ultimate branches are triangular; three, four, or five of them, united at their base, seem to form a small, star-like receptacle for each seed.

i. Is this plant internal, and should the alteration of the leaf be attributed to it; or, indeed, is it an external parasite which thrives because of this alteration occasioned by an internal plant?

In support of this latter opinion, one always finds in the thickness of the leaf, in the places where it is spotted with yellow, globules or tubercles of various sizes, which are perceived by placing it between the eye and the light, and which belong to a group of plants that are certainly internal. The latter are not uredos, at all, but nearly always accompany them. We shall speak of them below.

k. One would be tempted to place the small dichotomous shrub-like structure in *botrytis;* but it will be noted at least that each of the globules it bears is a spore, and not a capsule (*f.* and *g.*).

95. *a.* The leaves of purslane (*portulaca oleracea* L.) sometimes bear on their upper surface round tubercles, of a slightly reddish white, quite shiny, a line or two in diameter, very unequal, often irregular, not a little resembling the smallpox pustules. They begin as small white spots that gradually increase in extent and thickness. The leaves on which they abound are often hollowed like a spoon; they dry and fall before the others.

b. The raised epidermis breaks after a time, and reveals inside a white dust, which, observed under the microscope, shows irregular polyhedric fragments, trunks of pyramids or cones, which sparkle like crystals in reflected light. In transmitted light, they appear almost black; only the luminous parts are so distributed that several of these polyhedrons resemble gratings, and the truncated cones seem hollow.

c. When they are moistened, the majority take the form of an egg depressed circularly in the middle of its length, but almost imperceptibly, and having the small end much less rounded than the other. Some of them remain irregular, or become globular; these are the smallest. The former have a length of one and one-half times the diameter of the gemma of bunt, and a breadth of a little more than one diameter.

d. An hour or two after immersion, sometimes only 40 or 45 minutes, doubtless according to the temperature, which, while I have observed them, has varied from 12 to 16° R., the larger and more convex extremity opens so that the whole resembles a bottle whence a good part of the neck has been removed.

e. Very soon one globule appears on the outside, immediately followed by three, four, five, or six others, which come together in an instant in a ball, and move together for some time, the ball balancing or turning horizontally upon itself, or rolling in the liquid.

f. Ordinarily, the globules then separate, but sometimes they all remain together in such manner that one would not suspect, if he had not seen others like them, that this was an assemblage of several individuals. Sometimes two or three of them travel together, directly in contact or held by a sort of bond.

g. Those that separate, and they are the majority, are sometimes a little angular or tubercular, and, if I am not mistaken, hollowed like a boat, which makes them in certain situations appear to contain another globule. They resemble *bursaria;* but are very small, their diameter being only half or a third that of a bunt gemma.

h. They move like balls, but with much more agility. They leave no more doubt of their animal nature than do the majority of the animalcules, called *infusoria;* and I confess that I no longer believe that the latter originate wholly in the air, that is to say, that their germs, as has been thought until now, following too generalized observations, pass from the air into the infusions in which they are found. It will be seen that I have for my opinion still other reasons than those that may be deduced from the facts I have just given.

i. Little by little the movement of these globules slackens; they become fixed sooner or later, either at the surface of the water or at the bottom. The latter settle, enlarge, wrinkle, rupture, and assume the appearance of a formless mass of granules. This alteration doubtless arises from their extreme delicacy, which scarcely permits them to touch a hard body without being broken. Be that as it may, such has been the fate of the majority of those that I have observed. Others have maintained their globular form long after they have ceased to move. Still others, finally, and these are ordinarily the ones that come to rest at the surface, become a little larger and less transparent, which may perhaps be only an illusion due to emersion, which always tends then to augment. Next they put out a small, slender stalk, slightly twisted or undulated, articulated or granulated, at the end of which is formed a globule a little smaller than the animalcule that produced the stalk. Finally, this globule elongates into a body which assumes nearly the form of the pod or dry berry that contains the seeds of *capsicum annuum* L. The entire stalk then has a length equal to 6 or 7 diameters of a bunt gemma. This kind of animal growth stops there, at least within the temperature of 12 to 16° at which I have observed it.

k. I saw on cabbage a very similar growth that presented some like phenomena. The pustules are white and smaller; but they are often united in large numbers in irregular and quite

extended patches. The globules containing the animalcules become more generally spherical in water. These animalcules are a little more angular, especially at the time when they separate. Instead of becoming larger when they cease to move, it has seemed to me that they were smaller then. They nearly all sink to the bottom of the water when they die, but without becoming separated into granules, as those of purslane; at least that happens only to a small number. The stalks that they produce are more curved and more granular; when they reach the air, in growing, they terminate in a very irregular, elongated body. The animalcule, when this type of growth is advanced, is nothing more than a globular sac, so transparent that it is scarcely perceptible in water. On the interior is seen a more distinct and much smaller globule, which diminishes in proportion as the stalk grows.

l. The leaves of salsify also offer a growth of the same nature, which has been taken for an uredo. The globules containing the animalcules are a little larger and longer than in the cabbage and purslane. I have not yet been able to see these animalcules put out stalks.

m. In repeated experiments the emission of moving globules of the purslane has rarely failed to occur. That of the salsify on the contrary rarely succeeds, without my yet knowing why. These globules, however, always pass out after a certain time, but dead, or nearly without movement, often deformed, or several united in a single mass. The still-born globules of purslane do not produce stalks at all, any more than do those of salsify.

n. There is found on the two surfaces of the leaves of *amaranthus blitum* L., more often on the under surface, still another growth similar to the last three, with some slight differences, but from which I have so far seen only a very small number of living animalcules pass out. These put out no stalks at all. The tubercles that contain the white dust are much smaller than in the preceding species.

o. If one lightly scrape the bottom of some tubercles of purslane, amaranthus and salsify,[12] especially those of the last, and place the detached substance in a drop of water, he observes there

[12] I have as yet seen this growth in the cabbage only upon a piece of nearly dry leaf.

subcylindrical or conical pericarps, which open longitudinally, and sometimes expose two or three globules as large as gemmae of bunt, one of which is ordinarily ready to pass out. These globules differ from those that constitute the white dust, and that contain animalcules, only because they are younger.

96. Besides the moving globules just considered, a group of small bodies, apparently of vegetable origin, have very decided movements, though rarely so lively as those of these globules. I shall give some examples:

a. I saw a globule of the linear uredo, which had put out a large short stalk, shoot into the water an infinite number of excessively small corpuscles, which moved with great vivacity, nevertheless without much change of position, that is to say without going far away in a short time from the vicinity of the globule, but oscillating, going back and forth in short straight lines, or describing very eccentric little orbits. This phenomenon, which I have observed at other times, is very rare, and is doubtless only an accident. These kinds of monads can be found in gemmae, like certain larvae in fruits, without belonging to them. But the animalcules of purslane and of other plants that bear similar ones, are there too constantly and their course is too regular to permit the supposition that the same is true regarding them.

b. If one lightly touch the bottom of a drop of water, upon a glass, with the end of an ergot of rye or some other gramineous plant, he sees in the microscope ovoid, transparent corpuscles that, at a slightly raised temperature, soon take on very decided movements, although less lively than those of animalcules called *infusoria.* They also produce stalks (Pl. 3, fig. 9). Then their movement slackens; but sometimes the corpuscle and the stalk that it has produced still move together. The interior of the ergot contains much longer corpuscles of various forms, which appear to be composed of several of the former, and also move as they do, but less perceptibly.

c. I shall report, in a memoir that will soon appear, the means by which I assured myself of the spontaneity of these movements and of those of several other particles that are vegetable in appearance. Meanwhile, I shall give here a summary of my observations on this subject.

d. The seeds or gemmae of a great many microscopic plants, and perhaps of all of them, when they are sufficiently small and rounded, move perceptibly at a high temperature, whether at the bottom or at the surface of the water; but their movement is sometimes very feeble, and some precautions are necessary to perceive it.

e. Then, when they are crushed in water, particles of various forms and different sizes nearly always come out of them, the majority of which have a very decided movement. The gemmae of uredos and of bunt are of this category.

f. One observes, in a drop of water in which he has diluted a little of the interior substance of any kind of seed, of a kernel of wheat, for example, a large number of very small moving particles.

g. The same thing is observed in the juice from the root, the stem, the leaves, the flowers or the fruits of various plants.

h. The anthers of the stamens contain, as is known, globules that constitute the pollen or dusts. These globules are of various forms and different sizes. In water, their movements are like those that have long been noted, and the cause of which, ordinarily easy to assign, is purely mechanical. A kind of floating oil is detached from these globules, and some very small, rounded, unequal corpuscles emerge from them. These corpuscles move very decidedly, and it does not appear that any foreign cause can be assigned to this movement.

I find myself here in opposition to a celebrated scholar who honors me with his friendship;[13] and I confess that this would be a grievous presumption against the validity of my observations,

[13] "The anthers," he says, "like the other parts of plants, are nourished probably by juices elaborated in a pad found here at the base of the filaments, the anthers, and the globules. It is certain that the fluid of the dusts changes in proportion as they mature; this juice, at first very thick, becomes constantly more fluid. Bulliard has seen floating in the mucilaginous fluid, some globules or small bodies that seemed to him to be the fluid itself in a concrete form, as in the mallows and in stork's bill; but he did not see any of them at all in the '*dauphins des blés.*' *These little bodies are without movement.*" PHYS. VÉG. t. II. p. 78.

I think that M. Senebier, in these last words, speaks according to Bulliard, and not from his own observations. Perhaps the little bodies of which Bulliard speaks are not those I have constantly seen leaving the globules of various pollens. He saw only a few of them; those of which I speak are very abundant. Perhaps also this scholar did not see them move, because he observed them in a mucilaginous fluid, or at a too low temperature.

if they were not easy to repeat. I studied chiefly the pollen of the pumpkin, because everything in the flower of this plant is larger than in most others, and consequently easier to observe. When the globules of its pollen, taken from a freshly picked flower, are placed in water, there emerge from it an infinite number of corpuscles, which move at first from the impetus they have received, but continue to move for several weeks, and, consequently, a very long time after equilibrium has been reestablished. In order to restore this equilibrium and remove the causes of illusion, I place upon a flat glass a very small drop of water in which the globules burst. I am careful to have it very pure, and to examine it well in advance to make sure that it contains nothing foreign. I cover this drop with a little concave glass with flat sides, which can be surrounded with oil or wax. These corpuscles enlarge and several unite without ceasing to move, except for a few intermittences, provided the temperature be sufficiently high, as from 20 to 25° R. Sometimes even 12 or 13° suffices.

i. Globules of blood, under the same circumstances, that is to say, in water and at a high temperature, as is well known, have a slight movement like certain very small globules found in the eggs of several insects and invertebrates. They sink in water, and should not be confused with other larger, more unequal globules, which are perhaps nothing but drops of some kind of oil.

j. These various observations seem to prove that all organic particles, or rather particles that are organized or have lately been a part of a living organized whole, are disposed to movement, and that, in fact, they move in water for a very long time when their volume and form permit.

Some Microscopic Plants that Nearly Always Accompany Uredos and Uredineous Growths

97. Uredos are nearly always accompanied by another internal plant, which develops in the interior of the leaf or in the substance of the stem, and externally is manifest as brown, hard tubercles, always covered by the epidermis. One finds in these tubercles very unequal, opaque, reddish-yellow globules, of which the largest have a diameter equal to six or eight times that

of a bunt gemma. When placed in water, these globules burst and expel, sometimes with considerable force, transparent corpuscles, more or less regular and more or less elongated, according to the species. These corpuscles come out in two or three files that form a sort of chain or braid. Ordinarily, they separate quickly. They show a little movement, which is independent of the propulsion they have received, since they maintain it after equilibrium has been reestablished. After a few hours at a high temperature, they each put forth a small stalk. These corpuscles, in asparagus, are very long in proportion to their width; those of *atriplex patula*, which accompany the plant described in §94, are of varied forms, but, in general, ovoid and elongated, and the globules that produce them are green and semi-transparent when young. These globules, opaque in this species and in several others of the same genus, often appear to be suspended in another perceptibly larger and more transparent globule.

98. *a.* One often encounters among uredos small bodies of club, spindle, or pear, or very irregular shape, sometimes resembling puccinias, but of a very different nature, always composed either of several locules or of several distinct globules, unequal, naked, often colorless and transparent, and sometimes opaque. I have been tempted to regard them as the male organs of the uredos. Their origin, which I now know, has long intrigued me. Immersed in water, they quickly put forth from each node or locule branched jointed stalks, which in a short time make a considerable growth when the temperature is sufficiently high.

b. From various points on these stalks arise rows of globules, either simple or forming aigrettes or tufts, or dividing and subdividing into branches like little trees, each branch of which would be a row of globules. These globules enlarge, elongate and divide into segments or into irregular, rounded masses. In a word, they each form again small bodies similar to those that produced the stalks, and from which they arose. They are consequently some sort of bulb or seed with several germs, the last results of the fructification of the kind of plants that have been called *monilias*, but whose history it seems to me, was not yet completely known. It was not known, perhaps, either, that they are capable of completing and recommencing in water all the stages of their growth.

c. However, none of the monilias I observed offered me the complete cycle of their regeneration. I saw it quite clearly in one species that I shall naturally call *solitaire,* because only a single-headed thread starts from one point on the stalk. The globules take the form of a top. The base of the one nearest to the stalk is supported upon the point whence the fructiferous branch starts; upon the point of this one the base of another top-like structure is supported, etc. All elongate a little and divide transversely into three or four segments. These growths sometimes put out stalks, even without becoming separated from the rest of the plant. They are found among the globules of *amaranthus blitum,* which contain the animalcules because they grow on the leaves of this plant, and are mixed with them when the tubercles are opened or when the white dust which one wishes to observe is taken out.

d. I found on the leaves and dry stem of the onion a monilia in all the stages that I have just described; but it differs from the preceding species, principally in that the proliferous branches occur in tufts arising from the same point or nearly so.

e. M. de Candolle describes in *Flore française* three species of monilia. The clustered monilia is the only one I have recognized among those found with the uredos. I had found its bulbs or many-germed seeds on the leaves of lettuce with the plant I have described in §94 *h.* In water I saw them produce stalks that extended to two or three centimeters around the drop in which I had placed them. These stalks produced a large number of proliferous branches, whence a few globules fell after becoming slightly elongated, but did not yet take the form of the *puccinias* from which they arose.

f. As I am speaking here of these plants only on account of the seeming relationship that they have to the uredos, I shall not dwell upon the history of each species; but I shall describe one other of a genus not far removed, because, although it is not an internal plant, its fructification, all the gradations of which it is very easy to see by observing the status of several individuals at one time, appears to me to have the greatest resemblance to that of bunt.

99. *a.* It is manifest on both surfaces of the salsify leaf as a white dust, which covers it entirely, as if it were powdered with

flour. Under the microscope, this dust seemed to consist of ellipsoidal globules, of a length nearly double the breadth, and equivalent to twice the diameter of the bunt gemma. They appeared to be filled with small, rounded bodies of very irregular size.

b. Many of these globules are scattered; others are united end to end in the direction of their axis. These series of globules arise after the manner of the monilias from various points of a sort of network formed by slender filaments that cross each other on the leaf, and several of which arise from the same point. The globules are larger and more distinct as they approach the extremity of each series. Nearer the base, they are marked only by constrictions or slight transverse depressions; lower, by walls separating the cells in which may be seen small bodies of varied form, which are the embryos of the globules.

c. These globules, after a few hours in water at a temperature of 14 or 15° R., put out stalks similar to the filaments from which they originate. They arise from one of the extremities of the globule, a little to one side. Sometimes this germination takes place, although the globules are not yet separated, and one even finds on the leaf some of them that have produced stalks similar to those they put forth in water. These globules are then kinds of gemmae; but I have not yet seen them reproduce in water like the monilias. What makes it doubtful that this be possible is that the filaments seem to penetrate beneath the epidermis; so that when one examines them on the leaf by reflected light, and wishes to follow them in their course, he sometimes loses sight of them, or at least perceives them only with difficulty within a certain space, after which he sees them reappear farther on in the same direction, later to become hidden anew, etc. I do not know whether they draw any nourishment from the leaf; but at least they do not alter it perceptibly.

d. Each series of globules has a common coat, extremely fugacious, such as I imagine invests the bunt gemmae when they form in the kernel, and of which, because of that, one finds no more than fragments or a confused mass, difficult to recognize.

e. This plant differs little from the monilias; but one will separate it from this genus if he considers, among other differences, the ultimate results of its fructification, which are simple gemmae, while those of the monilias are multigerm.

100. In this growth, the proliferous branches, in which at first one distinguishes nothing more than in the stalk whence they arise, except that they are larger, appear later as tubes divided by partitions, or filled with oblong cells placed end to end. In each cell that is somewhat advanced is observed a small rounded body or a little mass of granules, which evidently is the embryo of the gemma. Of these embryos, the one at the tip of the proliferous branch matures and is detached first; the others follow. Each one reproduces a new stalk that gives rise to other proliferous branches, etc. Such is the extremely simple cycle of the regeneration of this plant and many others of the same class.

That of the uredos differs from it only in that their fructification must take place, or at least begin, inside another plant, where most often its progress or different stages can be seen; but the embryos that thrive at the tip of the proliferous branches of the uredos cause those directly underneath to abort; hence, the club shape assumed by the puccinias. Sometimes even, as in the puccinias of the rose, the epidermis of the pedicel, swollen towards the base, opens and reveals, when they are not yet well formed, a series of globules that appear to be the rudiments of another pericarp, destined to succeed the first, or to produce gemmae under the epidermis of the leaf.

Although the fructification of bunt does not appear in such an evident manner, the analogy, or what one is able to observe of it, permits no doubt that it takes place in the same way. From the tip of the stalks ending in the embryo, arise proliferous branches, partitioned, or formed of cells, like the aigrettes, stalks or branches that arise in the open air. Each of the cells contains the embryo of a gemma that matures in the embryo of the seed in proportion as the seed itself matures. These gemmae, as we have seen, are found more or less mature in the embryo of the kernel while it is still extremely young; but the walls of the tubes containing them are so delicate, and these tubes are so crowded in the limited space in which they grow, that they appear only as a confused mass of crumpled, extremely fragile membranes. But the proliferous tubes of the last plant that we described, as well as those of the uredos, forming in open air or in a place in which the walls are capable of yielding or of giving way to their growth or multiplication, whether by expanding or

being torn, assume a form determined by the number of gemmae that thrive at their extremity, and often are even very distinct from their first appearance in the substance of the plant they attack.

101. The fruit-like growths of the tufted stalks of bunt should be analogous to the puccinias of the uredos that succeed in maturing or forming in the open air; but, being unable to get nutriment sufficient or appropriate for their needs from the air, either in the water in which the gemma that produced them is immersed or in that in the body upon which it rests, they abort long before having attained the size they probably might reach if it were possible in these circumstances to provide them with a suitable nutriment. One cannot doubt that the tufted stalks are destined to penetrate into the wheat plant and to go into the embryo to fructify. They probably also would produce there puccinias, properly speaking, were it possible to introduce free circulation of the air there, or expand it sufficiently without disturbing the growth of the wheat. The tufted stalks that grow under our eyes on moist bodies are an image of what would occur then in this latter plant. In fact, this image is imperfect in that the fruit-like growths there would become much larger, and would assume the form of puccinias that become detached from the uredos, and might be able to function as these do. But, as we have already observed (§92), they would be useless, or at least superfluous, in the reproduction of bunt.

102. By all that precedes, I have incontestably established that the immediate cause of bunt is a plant of the genus of the uredos or of a very nearly related genus; that the growth of this plant, as well as that of the majority of the uredos, begins in the open air and is completed within the plant that it attacks. I have given a detailed history of this plant, founded almost entirely upon facts that anyone can easily verify: only a small part of this history is founded upon analogies; but these analogies are so palpable that they are in a way equivalent to observation, and scarcely leave any ground for reasonable doubts.

103. The majority of the plants of this class, which might be included under the general denomination of *internal parasitic plants*, or simply *internal plants*, are capable of making a part of their growth in water, or on very moist bodies. This presents an

easy means of studying them and of proceeding to the investigation of means of preserving useful plants from their ravages. This mode of observation can reveal interesting facts, which, without its help, one would not even suspect; such is the one I have described in §95, and of which I do not think anyone has yet had any idea. This mode of observation will enable us to discover methodically, and without having recourse to costly or cumbersome experiments, whose results, in order to be decisive, sometimes require several years, the surest and simplest preventive of bunt.

VII

Conditions That Inhibit the Growth or the Propagation of Bunt, and Those That Favor Them

104. From what precedes, one easily conceives why bunt is contagious, as several agriculturists and learned naturalists have long since observed.

105. It is further conceivable that in order that the contagion take place the bunt must occur either on the seed or mixed in the soil around it, or, finally, upon the young plant.

106. But this proximity or contact does not always suffice for bunt to be produced in considerable proportion, and the attendant circumstances are not without significance.

107. It is known that if the healthy seeds which are sometimes found upon the same head with the bunted[14] ones are carefully

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[14] M. Tessier regards as an unfathomable enigma these heads that contain "healthy and bunted kernels, and, what is still more difficult to explain, kernels partly healthy and partly bunted." (Art. *Carie*, Dict. d. Agricult. de l'Encycl. méthod. T. II, page 706.) Nothing is easier to find now than the answer to this enigma. Since bunt is a plant whose stalks and their branches invade the wheat stem and fructify in the embryo of the seed, it is conceivable that the number of embryos attacked, and the manner in which they are attacked, depend on the greater or less abundance of the stalks or branches that have penetrated the wheat plant, on their direction, or on causes that favor one of the two growths, that of the wheat or that of the bunt, to the detriment of the other.

The observations of §42 again explain perfectly why the bunt dust placed at some distance from seed sown upon the soil occasions infection.

I shall add that when a certain quantity of bunt dust is sown upon the soil, there appears after several days, especially when the temperature has not been very high, and when care has been taken to maintain a little moisture, a sort of short down, or light white crust, which I used to take for mould; but which, ob-

detached and sown the product is ordinarily healthy wheat. "The good seeds taken from a bunted head germinate and produce excellent plants." (V. Art. *Charbon* de l'Encycl. Édit. de Genève, T. VII, p. 309). This is an experiment I have performed several times, and in which I have always obtained healthy wheat without admixture of bunt.[15]

108. Now, it is true that among these seeds there always are some, about 1/12, that are only partly sound. I have said already that I had succeeded in gathering together some hundreds of them. The germ of these seeds is often intact; some are still capable of producing their plants; and, consequently, in these experiments, they should have produced some bunted plants; for, if the contact is ever established in an intimate manner between seed and bunt, it is in this case, where the latter occurs mixed, in some way, in the juice that must nourish the young plant. However, no bunt at all resulted. It appears then that contact alone does not suffice to establish infection. An experiment that I made long before discovering the cause of this malady might have made one think that it is not contagious.

109. I made some little packets, each containing the dust of several bunted kernels, with one or two sound seeds, the whole closely wrapped in several layers of tissue paper. I lodged them in holes several inches deep, which I made in muddy soil. Each packet gave one or two plants of perfectly healthy wheat.

It was precisely, as will be seen, the precautions that I took to assure infection that prevented it.

110. The bunt that I used was not of the current year; but,

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served under the microscope, appears to be composed of stalks of bunt, of aigrettes, etc., borne on gemmae, the majority of which are empty.

Such then is the bunt plant, which manifests itself to the naked eye, to all appearances, as a mould. This furnishes a simple means of ascertaining without the microscope the effect of preventives.

[15] "From a quantity of bunted heads," says M. Tessier (p. 698), "which supplied me with twelve ounces three grains of bunt, I recovered three ounces of healthy wheat, which I sowed. . . . This wheat, when it had been separated from the glumes, was blackened by the dust with which it had been mixed; it produced two-thirds healthy heads and one-third bunted. . . . "

M. Tessier says further, in accordance with M. Tillet, that healthy seeds taken from half-bunted heads produced a few bunted heads. But he does not say whether these healthy seeds had been separated from the others with sufficient precaution not to have been infected from them, and nothing can be concluded from this experiment relative to those I have made.

although I have since proved that the older it is the less capable it is of germinating, that which I used, being only two years old, could not have lost this faculty. I had no trouble in finding the reason for this singular anomaly when I arrived at an understanding of the immediate cause of bunt.

111. In fact, this disease being occasioned by a plant that begins to grow in the open air, I suspected that air was indispensable to it, and I soon confirmed this conjecture by experiment.

112. I next made several observations and experiments that prove that bunt can grow and thrive only inasmuch as its gemmae are disseminated or separated from one another.

113. I let some whole bunted kernels of wheat remain in water for a very long time, without any of the gemmae that they contained giving any signs of growth, except those to which cracks in the bran permitted free access to the external air. Some other bunted kernels, wrapped in tissue paper and treated in the same way, did not germinate, nor did the bunt dust tightly enclosed in tin foil. However, this same bunt, suspended later in the ordinary way, produced stalks, but fewer the longer it had been enclosed.[16] Thus, the seeds of wheat, wrapped in paper with

[16] For 65 days of the summer of 1806, I kept six kernels of bunted wheat wrapped in tin foil and immersed in common water that was able to penetrate it. The bunt became pale, and, when suspended later as usual, was unable to germinate.

For a long time the tin had borne on the outside, principally on the joints of the leaf, some small, semi-transparent, gray flakes of a light substance that collapsed when it was removed from the water, and resembled mould.

These flakes were formed of small cylindrical, much elongated tubes of different widths. They were gorged with globules with a diameter equal to theirs, pressed tightly against one another, almost like those of pollen in the lobes of the anthers of wheat before their dissemination. The largest were similar in size and shape to the mature gemmae of bunt; but transparent. Some tubes had emptied themselves, and their globules were seen strewn about them in the field of the microscope.

Doubtless in repeating my work, no one will take this plant for that of bunt, any more than I have. Several others of these are seen, even in preparations made with sufficient precautions, especially one that might more easily be mistaken, and bears globules very similar in color and size to the mature gemmae of bunt. In observations followed with too little perseverance, they might lead one to think that this latter plant is capable of completely reproducing its seeds in water, and that they can mature there. But these globules are smoother than the gemmae of bunt. They never appear engine-turned and they mislead the observer who expects to see stalks and aigrettes come from them. They resolve themselves into a multitude of little grains which reproduce similar globules borne on pedicels that arise like pins from a very long and very branched stalk.

the bunt, will have germinated without it; and, although the wheat seedling, in coming up, should carry some gemmae to the air with it, it will have left them in its path in passing through the paper and the soil packed over it. If a small number came up, they would not suffice to produce infection; for it is probably true of the seeds of this little plant, as of all those that are excessively numerous, that many perish for one that achieves its end.

114. I further observed that very dry wheat, dusted with bunt that also is very dry, does not ordinarily become very bunted, unless this operation be so conducted as to sow much of the bunt with the wheat.

115. In order for the wheat to produce many bunted heads, it must be moistened before it is inoculated, or fresh bunt must be used on wheat that is still soft, or, for greater certainty, the wheat must be allowed to begin germinating in water in which some bunt of the current year has been suspended, and sprinkled with this suspension again at the time of sowing; then few plants escape infection: sad secret, indeed; but the means of obtaining the highest degree of infection are also the best suited to test the efficacy of preventives.

116. When wheat is thus infected, the bunt germinates some days later on the sprout to which it is attached, and that has brought it into the air. Thus the conditions attending it are the most favorable for producing the aigrettes or tufted stalks, which penetrate the sprout. This agrees perfectly with what I already have proved, that the introduction of the bunt plant into the wheat plant is possible only at the time of the germination of the latter, or very soon afterwards.

117. The results of the ingenious experiments made by M. Tessier, in order to discover whether certain parts of wheat seed are more susceptible to contagion than others, explain why it is necessary to moisten the grain before applying the bunt to it when one wishes to succeed more surely in infecting it.

"I dipped," he says, "the point of a pin into some of the moistened bunt dust, with which I impregnated only the upper part of the germ of 140 kernels of wheat, after a washing and liming capable of removing from it even the last vestige of bunt; 140 kernels of the same wheat were smutted in the groove, and

140 in the tuft. These different kernels were sown in three separate rows, at equal distances, in the open field, in the midst of a large number of other experiments. The 140 seeds inoculated on the germ produced 40 bunted heads; the 140 inoculated in the groove produced 21 of them; and the 140 inoculated on the tuft bore only 10." (*Art.* Carie, *already cited*, p. 704.)

M. Tessier later repeated this experiment on a larger number of seeds. The results were not strictly the same each time, probably because of the conditions; but each time he had many bunted heads; and, in general, the kernels inoculated on the germ gave more of them than those inoculated on the tuft or the groove.

It is clear that the germ of wheat, in developing, probably encounters more of the seeds of bunt the nearer they are to it. If they are only upon the little tuft at the other end of the seed, the plumule, in turning and curving around the seed, must go there to meet them. Now, although that happens quite often, because it is rare that the seed is placed with the germ above, it is conceivable nevertheless that the encounter of the germ and the seeds of the bunt should be much less frequent in this latter case than in the former. If, then, some very dry bunt powder is dusted on seed which is also very dry, only the tuft will retain it: the rest will slide off the seed either during sowing or covering. Rains often will wash off what manages to remain. On the other hand, if the seed or the bunt is moistened, the latter will stick on the entire surface of the former by means of the gluten with which it is provided, and it will be found on the germ in large enough quantity that the plants which will arise from it may penetrate in sufficient number.

118. M. Tessier regards the bunt dust as a virus, and he points out how great its activity is, since such a small quantity as he could take with the point of a pin, "applied to clean seeds, at certain points only, is capable of spoiling so many heads"; for, he adds, "in certain rows of inoculated seeds, often a third or a half of the heads were spoiled." But this very small quantity of bunt contained thousands of gemmae one of which alone, in favorable circumstances, might have been sufficient to poison all the heads of an individual wheat plant.

119. Our present knowledge of the cause of bunt explains so

naturally all the phenomena pertaining to it, and concerning which reasonable doubts cannot be raised, that this alone, assuming it to be only a matter of a simple hypothesis, would constitute a marked presumption in its favor. One will further be convinced of it by attempting to apply it in explanation of the numerous and important observations by which MM. Tillet, Duhamel, and Tessier have enriched science.

120. One only of the experiments of M. Tessier does not at first appear to be in accord with the well-ascertained fact that bunt is a plant of a kind approaching that of the uredos, the grain or the seeds of which form the black dust that fills the bunted kernels. This experiment follows:

"By chemical analysis of bunt, I had obtained," says M. Tessier, "different products, a thick oil or sort of butter and an extract. I attempted to inoculate with each of these products, as I had inoculated with the bunt dust, which had not undergone the action of fire.

"The inoculation with the thick oil produced as much as a quarter and even nearly a third of bunted heads; and that of the extract produced nearly as much as a third of them."

But it is very probable that part of the dust passed with the oil, or ahead of it, at the beginning of the chemical operation, without having been exposed to a heat severe enough to destroy in the gemmae the faculty of germination. Another part could remain in the same manner in the extract or gain access to it after the operation. It is conceivable that the air and all the utensils of a workshop where this dust was analyzed could serve as vehicles for it; and its effect was then the more assured, since a tenacious substance held it on the wheat.

There should, therefore, be nothing in this experiment that cannot easily be explained by the introduction into the wheat plant of a parasite that begins to germinate outside; and I venture to say that bunt will not be inoculated with oil that is entirely purified from the dust that the bunted kernels contain; that is to say, with such oil that, in examining it under the microscope, one sees none of the globules of which the dust is composed, and which are the gemmae or the spores of this growth.

121. Bunt suspended in boiling water very quickly loses its germinability. It loses it after a few hours in water at 50° R. and,

when it has remained for some time in water at 40°, it produces, everything else being equal, far fewer stalks than that which was not subjected to this degree of heat. It did not produce any of them at all, at least at a not very high temperature, when it had been exposed dry and spread out for four or five hours, at a temperature of 56° R. But such as sticks tightly, as it were, to the wheat that it contaminates can endure this test much longer without being so much altered by it, because of the moisture the grain furnishes it in proportion as its own evaporates.

"I tried," says M. Tessier, "treatments from 20° of heat up to 80°, and I assured myself that the diminution of bunt was not at all because of the degree of heat of the treatment, and that it was indifferent to heat at 20° or at 60°."

But bunt does not undergo, during liming, a temperature equal to that of the liquid in which the wheat is immersed, or with which it is sprinkled; that depends also on the temperature of the wheat and on its bulk, compared to that of the liquid.

Several times I sowed bunt-dusted wheat upon which, after having placed it in an earthenware vessel, I had thrown enough boiling water to wet it well. It did not come up so well as did wheat treated in the same way without having been scalded; but it always produced less bunt.

122. Very severe frosts hinder but very little, if at all, the growth of bunt, provided they do not occur too near the time when it begins to germinate.

123. The older the bunt, the longer the time required for its growth to begin, all other things being equal; and, when it is very old, it does not germinate at all. M. Tillet inoculated seed for 20 years with bunt dust of one and the same year; little by little it lost its activity until it no longer produced any effect. This agreement of results obtained by such different means is remarkable.

I dusted wheat with bunt six years old. It did not give so large a proportion of bunted heads as that inoculated with fresher bunt. About 15 months later, this same bunt was unable to germinate in water at a temperature of 10 or 11 degrees; it germinated when the temperature was raised; and six months later, that is to say, about eight years after having been collected, it could no longer germinate at all, however high the temperature. That of

M. Tillet was kept in a sound state for a longer time. This may depend on the climate and several other conditions, as happens with various seeds. I tested some five years old, which germinated 24 hours later than that of the current year. In some way, I hastened the effect of time on bunt by exposing it often to the heat of the summer sun in glasses covered by paper.

Bunt, detached, either by washing or by agitation while dry, from a little wheat that had been thus treated, could not germinate at a temperature that varied, while it was soaking, from 14 to 11° R.

124. Bunt, alternately moistened and dried, in the shade or in the sun, does not lose its germinability, provided it is not allowed to dry at the time when it begins to grow, or too near this time, and provided the temperature is not very high during the experiment.

125. Bunt, washed with the most scrupulous exactitude, nevertheless germinates about like that which has not been washed. It then loses its fetid odor, and assumes one resembling that of cinchona. It gives a rather pretty, yellowish green color to water in which it has remained for some time. The first waters are extremely fetid, especially when the bunt is fresh. Probably this water contains the altered gluten, whose analysis MM. Fourcroy and Vauquelin have given in a memoir, read at the Institute in the year 13. But I presume that the analysis of the spores of well-washed bunt would give different results from those these celebrated chemists obtained from the entire bunt.

126. In general, bunt does not germinate in water in which acids, alkalies, salts, alcohol, or camphor have been dissolved or mixed, even in very small proportions. But these substances do not always thereby destroy the vegetative faculty, and it often suffices to wash the bunt in pure water, for it later to grow as usual.

127. Of these substances, a few, among those sufficiently soluble in water, permanently destroy the faculty of germination in bunt, even when it remains in them only a short time and is later washed in pure water.

128. The numerous experiments performed by MM. Tillet and Tessier on bunt-contaminated wheat, and from which they have deduced some more or less preventive methods, are per-

fectly in accord with those whose general results I have just given, and that I have made directly on the germination of bunt; but the substances with which these scholars have terminated [their experiments] do not appear to me to combine all the qualities that constitute a convenient and economical preventive. We shall see how the discovery of the cause of bunt has led me to that of this preventive.

VIII

Some Preventives

129. Having proved, as we have seen in the preceding section, that an infinite number of substances when placed in water give it the property of destroying the germ of bunt spores, it remained for me to investigate which of these substances combine in the highest degree all the qualities of a preventive applicable to agriculture. I had begun to proceed methodically towards this, when a fortunate incident considerably shortened this work.

130. Having washed some bunt with several changes of well water, then with water that had been distilled in a large copper alembic, and having left it for some time in a glass goblet containing this water, I placed drops of the water from the goblet, containing several hundred gemmae or spores of bunt, in a watch glass half full of highly purified distilled water. To my great astonishment, these gemmae either did not germinate or germinated very poorly, whereas some others, in similar circumstances save for the copper, germinated as usual. I decided then to direct my researches first and principally towards copper and the copper salts.

131. Scarcely had I begun to apply myself to this, when a friend of mine, to whom I related what had happened, told me that, on an estate at Villemade near Montauban, where every year he sows about 20 hectoliters of wheat, steeped in milk of lime prepared in a large copper cauldron, he never has any bunt, while the neighbors who steep it in a wooden vessel, as is generally done thereabouts, very often have it, and sometimes in very large amount.

132. A little later, M. Lagravère, deputy mayor of Montauban, told me apropos of my observations, that for a long time he

had no bunt at all in one of his fields, where a large basket-shape copper vessel, pierced with many small holes, was used for steeping. Neither M. Lagravère nor the proprietor of Villemade suspected that the copper was of consequence in this effect, and they supposed that the liming was done with more care at their places than at their neighbors'.

I visited the Villemade estate at the approach of harvest time. I found, in fact, much less bunt there than in the neighboring fields, and the difference sometimes varied from a half to 1/150 of the number of heads. It was especially conspicuous in a small remote field enclosed by quite a large piece of land, although the two were separated only by the common hollow of the furrows; so that, in walking around the furrows that served as limits to the two fields, one found much more bunt on the side of the small one than on the other.

134. I was shown the copper vessel. It was encrusted within by a calcareous layer, which covered another one of verdigris. The latter could be seen in small places, which might form in all about a square decimeter, where the former had become detached. The effect probably was due entirely to this verdigris; but it did not prevent absolutely, for there were some parts of the harvest, rare, it is true, principally in the shade of the house and groups of large trees, in which bunt was found in the proportion of 1/50 or 1/40. Besides, the effect of this liming should vary each year, according to the extent to which the layer of verdigris was uncovered or encrusted; but, upon this year's crop, this effect is the less doubtful because, independently of the proofs I have just given, there exists another very striking one. Some maslin had been sown that had not been limed, and of which the wheat produced a large quantity of bunt.

135. I later requested M. Lagravère to inform me in detail concerning the manner in which he did his liming.

The copper basket is filled with wheat; it is immersed in milk of lime mixed with a little sheep's urine; it is then placed upon some cross pieces above the tub containing the liquid, in order to let it drain, etc.

136. In observing this basket, which was smaller and still more encrusted with carbonate of lime than the Villemade cauldron, I suspected that its effects would be inferior, and I was

very soon convinced of it. On the whole, however, M. Lagravère had little bunt, and not nearly so much as his nearest neighbors.

137. The most of it occurred, as at Villemade, in the shade of large trees and of habitations. Several other observations and the information I procured convinced me that shade favors the propagation of bunt, although it can not give rise to infection when the spores of the internal plant are not present.

Shade can produce this effect by inhibiting the growth of the wheat plant. The more vigorously the wheat grows, all other things being equal, the less it is subject to bunt; and, reciprocally, the bunted plants are generally less vigorous, or shorter, than the others. This has been observed earlier by others, but I saw it this year (1807) in a very striking manner. In 1806 I inoculated 56 decagrams of wheat. I washed a part of it, which I sowed in November. At the same time, I sowed the rest, taking the necessary precautions in order that there be no confusion. From the middle of April, a great difference in the height of the plants of the two parts was noticeable. However, the part that had been washed was not free from bunt: this disease had attacked 1/50 of its heads and six-sevenths of the others.

Shade further favors the propagation of bunt by maintaining a certain degree of moisture; and this is not at all contradictory to what MM. Tillet and Tessier have proved, that fogs are not the cause of bunt; for, without being the cause of it, they can favor it.[17]

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[17] M. Tessier regarded fogs as the cause of rust; but it is proved today that they are no more the cause of rust than of bunt. How could fogs be the cause of a plant? They are able at most to favor its propagation, which, nevertheless, is perhaps not yet proved. In March, I sowed wheat that became more rusted than some of the same wheat sowed in autumn, and much less so than some of the same sowed in April. The rust seems then to be in inverse relation to the total duration of the fogs to which the wheat was exposed. Some observers have maintained that the rust appears all at once; that in an instant everything that grows in a vast country is affected by it. This is an error. At least, it is certain that it does not happen thus everywhere. The rust of the leaves of wheat, the linear uredo of de Candolle, appears little by little, and ordinarily very slowly. Sometimes the lower leaves of the same plant are laden with it, while none of it is yet to be seen on the leaves above. At other times certain plants bear it, while in the same field other plants do not. It often happens also that wheat is much rusted and that other species of plants do not show any rust at all. Moreover, the rust that attacks one plant is rarely the same species as that attacking another; and, when it begins to appear externally, it is found in the interior of the leaf if one searches carefully.

Effects of Copper on the Germination and Development of Bunt

138. Ten or 12 milligrams of fine copper dust prevents bunt from germinating, when mixed with some of it and suspended in 15 decagrams of water. A sheet of yellow or red copper of 15 square centimeters, scraped or not, either from base coin or from bell metal, produces the same effect.[18]

In order to attempt to determine the limits of the influence of copper on the germination and development of bunt, I used a thoroughly scraped sheet of this metal, the total surface of which was 15 square centimeters (2 inches).

I let it soak for a longer or shorter time at the bottom of a tumbler in three decagrams (one ounce) of ordinary water. I removed it, more or less oxidized, black, brown, or iridescent. I next made a suspension of bunt in this water and left it there until the bunt germinated or the time for its germination had long passed.

140. This sheet must remain 60 or 72 hours in the water, in order that the latter, at a temperature of five or six degrees, produce a well-marked effect upon the growth of bunt. Then it either does not germinate at all or germinates very poorly and produces only deformed stalks. These stalks are found only at the surface of the water, and no sign of growth is found at the bottom.

141. Similar effects are obtained from the prolonged stay of water in very clean copper vessels; but, when it is shaken often, especially if there is a little verdigris, or carbonate of copper, etc., on the surface of the copper, the effects are much more marked.

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[18] If, as it seems, the ancient Greeks or the ancient Romans were not acquainted with bunt, it probably was due to the brass they frequently used in their farming implements.

Dalechamp says, in his *Histoire générale des plantes*, that Theophrastus and Pliny spoke of *blight*, or *smut*, under the names of ερυσιδχ and *carbunculatio;* but neither these authors nor Dalechamp makes mention of *bunt*, which accords with what Ginani says, that this disease was entirely unknown in all Lombardy before the year 1730.

Would all the time that elapsed from the time when they no longer made any great use of brass in Italy up to this period have been necessary, in order for this disease to recur? But lands impregnated with copper for long ages may be protected for a long time. However this may be, its recurrence should not be attributed, as Ginani thinks, to a change in climate.

142. The extent of the copper surface moistened by the water cannot take the place of time, unless it be very great; for, when it was increased nearly tenfold, and when the water was left in it only 20 hours, the latter did not perceptibly inhibit the germination of bunt held in suspension in it.

143. Applied to agriculture, these procedures would be subject to several disadvantages. They would require much time and could be of use only for small quantities of seed. I next undertook to determine carefully the effects of various copper salts on the germination of bunt; but copper sulphate (commercial blue vitriol), being both easier to procure and subject to fewer disadvantages than the others, particularly interested me.

Some Effects of Copper Sulphate on the Germination of Bunt

144. I had noted that it was sufficient for the water in which the bunt had been suspended to hold in solution a very small proportion of copper sulphate, in order to prevent it from germinating; but I wished to know to what point this proportion could be diminished without losing the effect. I then performed experiments with smaller and smaller quantities at a temperature of 5 or 6°, at which bunt consequently takes a long time to germinate. I found that the constant presence of this salt in the proportion of 1/280,000 of the weight of the water prevents all germination; that 1/600,000, or even 1/1,000,000, retards it perceptibly; that a solution of 1/10,000 by weight of this sulphate in water suffices to destroy the viability of bunt soaked in it for one or two hours, even though it be washed immediately afterwards; and that, in experiments of the kind last mentioned, much less time or less sulphate retards germination.

145. According to the experiments of M. Proust, copper sulphate, such as I used, contains 35 per cent of water of crystallization. Thus, the real sulphate necessary to give water the faculty of preventing bunt from germinating in it at a low temperature is less than 1/400,000 by weight, and 1/1,200,000 retards its germination.

146. In repeating these experiments at higher temperatures, I sometimes found that bunt germinates in water containing 1/200,000 of its weight of copper sulphate, and that 1/10,000

does not destroy its viability, when it is washed, after having been allowed to soak only a few hours in the solution.

147. These differences are not surprising. At a high temperature, the more active viability either does not give the preventive time to act or more strongly resists its action.

148. But, as was more difficult to explain, at a very high temperature things sometimes happen as they do when the temperature is much lower.

149. I suspected that this might arise from the dryness or moistness of the bunt. If it is very moist when placed in the solution, it is clear that, being already soaked with water, it absorbs less of it than when dry.

150. In order to assure myself of this, I took some very fresh bunt that I had just collected and exposed part of it for a few hours to a very hot sun in a window with a southern exposure, where the decimal thermometer rose to 56°. In three glasses, A, B, C, I made suspensions of the bunt thus dried, the first with pure water and the second with the preventive at the *minimum*. I soaked the third for three hours in a solution containing 1/10,000 of its weight of copper sulphate and then washed it. At the same time, I prepared three other glasses, A′, B′, C′, respectively, like the first, with some of the same bunt, which had not been dried. These latter suspensions, as well as A, grew about as usual; B and C produced nothing.

151. It should be noted that when the preventive does not act so well as usual under conditions that at first glance appear identical, the growth is manifest only at the surface of the water, and none or scarcely any of it is found at the bottom; whereas in pure water the gemmae that remain at the bottom, and are much more numerous than those at the surface, nearly all put out long bare stalks, when they are not stuck together in too large numbers.

152. When the sulphate is dissolved in ordinary water,[19] as I nearly always do in these experiments, in order that they may be more applicable to practice, there forms a bluish or greenish-white precipitate, which remains suspended in the liquid a very

[19] The ordinary water I use is very clear and good to drink and contains scarcely 1/2,800 of its weight of foreign substances in solution. These are principally calcareous salts and muriate of soda.

long time, and probably is a mixture of sulphate of lime and carbonate of copper. The copper sulphate then is decomposed in greater proportion as its quantity in relation to that of the water is decreased; so that, if a very weak solution is filtered, the liquid that passes through does not produce nearly so great an effect.

153. Does the precipitate act upon the bunt; or, indeed, could the filter act upon the sulphate? However it be, the precipitate and the solution in which it is suspended act, together or separately, upon all the bunt that the solution is capable of completely wetting.

154. With distilled water I tried 1/200,000 of its weight of sulphate; but at a high temperature it produced almost no effect. With 1/100,000, on the contrary, bunt gave absolutely no sign of growth. With 1/8,000, letting it remain in the solution only a few hours and then washing it, it grew almost as in pure water. Treated in the same manner for only a half hour in 1/2,400 at a temperature of 11° R., it was unable to grow.

155. These experiments have been repeated, for the most part, many times, especially when their results presented some uncertainty. They require more time and care than one would at first imagine; although, in general, they yield within a few days results analogous to those that would require eight or ten months in the field.

156. I am giving here only the summary of the experiments on bunt that I have tried in order to determine the limits of the action of copper sulphate and the manner in which it acts when dissolved in small quantity in ordinary water, the lengthy details seeming to me to be unnecessary.

The first point needs little more attention; the second would still require many experiments, to which I propose to give my attention.

Test of Copper Sulphate and of Copper on Wheat Dusted and Sown in the Open Field

157. Towards the middle of March of this year (1807), before having made the majority of the experiments, whose results I have just given, and as soon as I had made enough of them on copper and the copper salts in relation to the germination of bunt to discover their efficacy as preventives, I prepared several

samples of wheat, and sowed them in the field, although it was a little late.

I had (1) left some well water for 48 hours in a large pot made of red copper, which was slightly oxidized or tarnished by a little verdigris, stirring it at times with a stick. Into this water I put some wheat dusted according to the first procedure described in §115. I later took it out and let it drain, and then dry on paper in mild sunlight. (A)

(2) I filled the same pot up to the height of five or six fingers with boiling water. When this had cooled again, I immersed in it some bunt-dusted wheat, which I treated like the preceding. (B)

(3) I dissolved six decigrams (12 grains) of copper sulphate in a quantity of water sufficient to moisten well 15 hectograms of infected wheat. The wheat was worked up in this water with the hands; and when it had soaked it up, it was spread out upon paper, on which it was dried like the others. (C)

(4) I did the same thing with 36 grains of sulphate, instead of 12. (D)

These samples were sown with some others in the order in which they are shown, with the results, in the table of §162.

158. Having washed some seed from each of these samples of wheat, and having placed the washings in glasses full of water, I found that the bunt gemmae or spores that had been detached from A germinated only very tardily, and produced but a few very short, deformed stalks, from which no growth ensued; that the gemmae from B germinated as usual; and that those of C and D did not germinate at all. From this I had to conclude *a priori* that A, C, and D would yield no bunt, and that B would yield as much of it as if it had not been prepared after having been dusted, or that it would yield as much as if, after having been dusted, it had been passed quickly through some pure water.

159. It is not easy in this country to have things done as one wishes by peasants: their awkwardness or their unwillingness nearly always occasions some derangement in the experiments.

Various circumstances obliged me to have this wheat covered by the plough, and prevented me from supervising the operation to its finish. The result was that parts A and B, which were

162.

Wheat sown without treatment. Inoculated wheat, sown with or without treatment.

Soaked in water that had been left two days in a copper pot, in which it was stirred from time to time, rubbing a little upon the copper: one-sixth bunted.

Soaked in water that had boiled in the same pot, after this water had been cooled: one-sixth bunted.

Well moistened in a solution of copper sulphate containing this salt in the proportion of four decagrams to each hectoliter of wheat: 30 bunted heads among about 3,000.

Id. 12 decagrams of sulphate per hectoliter: 9 bunted heads among about 3,600.

Limed: 1/50 bunted.

Inoculated, not treated: one-third bunted.

About 1/150 bunted.

Note. *According to observations made on the bunt detached from B in washing it after treatment, it should have given a great deal of bunt. A, on the contrary, should not have given any at all if the two samples had not been mixed in covering them with the plough. The little bunt there was in C and D surely arose from the same cause.*

separated by only a small space, because I did not at first regard the difference between their anticipated results as very important, were entirely confused, especially because they were placed at an end of the field where various causes contributed to this effect.

160. A, according to the experiments performed on the washings, should have been much less bunted than B, or rather should not have been bunted at all.

But the results of these two trials are scarcely of practical significance, because copper thus employed has some disadvantages, as we have seen, and it is not necessary to have recourse to it.

161. If, on the other hand, one compares A, B, E, and especially F, with C and D, the effect of the sulphate will not seem doubtful. The nine heads of D are an insignificant quantity, and arise without doubt from F or E. It is conceivable that the plough-share or the feet of two oxen and a man, which pass and repass several times upon the same furrow, could well transport a few seeds from one part to the other, in spite of the care taken to leave quite wide spaces between them.

163. After this wheat was sown, experience having taught me that the efficacy of copper sulphate was much greater than I had at first supposed, I attempted some other tests in the field with smaller doses. They were sown and very carefully covered. Nothing should be mixed this time. But the season, already too advanced at the time of the first tests, was then still more so: it was in April. Only very little rain fell afterward, and this wheat gave too few heads to warrant any inference relative to practice. Nevertheless, if one wished to attach significance to these results, it would follow that two decagrams of copper sulphate, instead of 12, would suffice to protect completely each hectoliter of wheat.

In 1789, M. Tessier sowed some wheat that had been washed in a solution of copper sulphate, and found that it produced no bunt. However, this experiment could not prove anything, since it was made with wheat that, sown without treatment, yielded a crop only 1/1,800 bunted (Art. *Carie*, p. 721), a quantity that, in experiments of this kind, should be regarded as of absolutely no importance. It appears, moreover, that the solution was very strong, since the wheat, when dry, was spotted with blue, and the preventive would have been very expensive. Thus, M. Tes-

sier was not impressed by it. In fact, he had no reason to be, since copper sulphate, in this experiment, gave no more promise than several other substances that he tried at the same time. M. Tessier then discarded this preventive with several others, such as pure lemon juice, ether, mint brandy, pure brandy, oil of hartshorn, etc., which he had tried only out of curiosity.

Effects of Copper Acetate and of Some Other Metallic Salts or Oxides on the Germination of Bunt

164. It appears, according to the few experiments I performed on crystalline copper acetate, that it acts on bunt nearly like the sulphate. I did not devote much attention to it; but I tried, as being more applicable to practice, some experiments on the effects of common vinegar in which copper had been left.

165. I first found that the quantity of copper that the vinegar I used[20] could dissolve in a few days at a temperature of 20 to 22° amounted to 1/3,000 of its weight.

166. Three grams of this vinegar, holding in solution 1/3,000 of its weight of copper, mixed with 27 grams of water, destroys the germinability of bunt suspended in it for four hours at a temperature of 18 to 20°. Now three grams of this vinegar contain a milligram of copper, which, according to the experiments of M. Proust, gives nearly three milligrams of acetate, that is to say, 1/10,000 of the weight of the liquid. But, when the bunt is left in it only two hours, or when only four decigrams of the same coppered vinegar are mixed with 27 grams of water, the germination is only retarded, and some bare stalks are found at the bottom of the water.

167. I repeated the same experiments with vinegar weakened in different degrees, and always obtained results proportional to the copper it had dissolved; but, the weaker the vinegar, the more slowly does the solution take place.

168. Some experiments performed on sulphuric acid and on vinegar seem to prove, concurrently with those I made on copper, and I have already reported, that the effects produced by copper sulphate and acetate on bunt are due principally to copper, or rather to copper oxide, since iron sulphate does not con-

[20] In order to saturate 45 grams of this vinegar, it was necessary to use one gram of chalk called whiting.

stantly produce like effects, unless it be employed in much larger proportion.

169. It appears from the experiments I performed directly on bunt with white oxide of arsenic, which is used in York County, England, that it can produce a quite marked effect as a preventive. But its energy is much inferior to that of copper sulphate. Iron sulphate, to judge by a small number of experiments, would produce as much effect, and in this case would be much preferable. It costs less by half, and dissolves promptly and in large proportion in cold water, which dissolves arsenic only in small quantity. It is necessary to reduce the arsenic to a very fine powder and boil it a long time (at least such is the English practice). This does not fail to complicate the process greatly and to multiply the chances of the dangers that are encountered in using this terrible poison, which, moreover, it would be very imprudent to place in everyone's hands.

170. Superoxygenated muriate of mercury (corrosive sublimate) is highly potent; but it is too expensive and dangerous. M. Tessier, who obtained some success with these substances, formally advises avoiding them and reports some instances of grave accidents they have occasioned. They, nevertheless, prove that anything that destroys the germination of bunt is a preventive of infection.

The Method of Using Copper Sulphate on a Large Scale

171. Having treated about 50 hectoliters of seed with copper sulphate this fall (1807), I am going to describe the method that seemed to me the surest and most convenient.

One places in a tub as many times 14 liters of water as there are hectoliters of wheat to be treated, and dissolves in it as many times nine decagrams of copper sulphate.[21] There are two other

[21] This amounts to nearly 23 pints of water and four and one-half ounces by light-ounce weight of copper sulphate for each 12 bushels of wheat, Parisian measure.

The solution of the sulphate requires a few hours. It may be hastened by crushing it, by stirring, or by dissolving it in a small quantity of boiling water.

When the operation must be of long duration, it is better to prepare solution for only a part of the seed, and to add water and copper sulphate to it in the prescribed proportions. In order to give the salt time to dissolve, this can be done during intervals of rest.

After some of this solution, in which much seed had been treated, had been

vessels, each with a capactiy of two or three hectoliters. Twelve or 14 decaliters of wheat to be treated are thrown into one, and some of the solution is poured into it until it rises to several decimeters (5 or 6 inches) above the wheat. It is stirred well, and all floatage is carefully removed. Some wheat is placed in the second vessel, and treated in the same way. Some cross-pieces are laid upon this second vessel, and on them is placed a basket of such texture that it lets the water pass freely, without letting the grain pass. When the grain in the first vessel has remained under water for half an hour, it is dipped out with a *copper hand-bowl*,[22] a certain quantity of the liquid being taken at the same time. This is briskly thrown back, in order to free the wheat from any floating material that may remain. This wheat is then thrown into the basket; and, when the basket is full and the wheat has drained sufficiently, the latter is placed in a heap. When scarcely any more wheat remains in the first vessel, more is put in, stirred, skimmed, etc. The basket is placed upon this vessel and the manipulation is from the second to the first, as it was from the first to the second, etc.

Wheat thus treated is soon dry enough to be sown. If, however, it were necessary to keep it a long time, it would be well to stir it occasionally.[23]

172. Anyone can vary this process in his own way, according to the hands and utensils at his disposal. It suffices to proceed so as to attain the same ends, that is to say, the wheat must stay in the solution a half-hour, or more if desired, for there is no harm in this, and no bunted kernels must be left.

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kept for eight or ten days, a thick bed of mould was found in it, and the solution took on a green color. Evaporated after having been filtered, it furnished no crystals of copper sulphate, but yielded other small greenish-white crystals, mixed with a dull green substance.

In spite of this alteration, a quart of the solution, mixed with three quarts of water, destroyed the germinability of the bunt of the current year, which I left in it for 25 minutes.

[22] Deep and long-handle copper bucket.

[23] Fowls can eat it without injury. With it alone, I amply nourished a four-month-old chicken for six days. On the last day, I even fed it wheat freshly taken, after an hour's soaking, from the solution used for its treatment. This chicken kept quite well on this food; and, although fowls and pigeons rush avidly upon fields that are being sown, it has not been observed that this has injured them.

173. It is understood that one must avoid contaminating anew the treated wheat, either with the dust that escapes from severely bunted wheat in motion, or by transporting it in bags soiled by this dust.

174. However contaminated the seed may be, the treatment we have just described will destroy the germ of the bunt; but, since whole bunted kernels are not easily penetrated by the solution, there would be danger that some of them would still be left after the operation, if the wheat that is to be treated should contain a large quantity. In this case, then, it is essential to free the wheat from them by one of the most convenient methods.

175. Nevertheless, in doubling the dose of sulphate[24] and the time of immersion, and stirring and skimming as I have prescribed, I have every reason to believe that there would be nothing to fear from their influence.

176. It must be noted further, that the effect of the solution is more certain, the drier the seed is when immersed in it. If it were very moist, there would be danger that effectiveness would not result, or that it would not be complete. It would not be advisable, for example, to wash wheat beforehand to free it from bunted kernels unless it were later well dried.

177. If one worked with only a small quantity of wheat, it would be necessary for it to contain no bunted kernels; because, without increasing the dose of the solution or using a vessel very deep compared with its diameter, it would perhaps not cover the wheat sufficiently to permit skimming it. But there should then be no harm in leaving it there five or six hours, stirring it well from time to time. This should destroy the germ of bunt to the center of the bunted kernels. But, in any case, when it is not a

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[24] There is nothing to fear from even a much stronger dose. I had to put in 16 times more of it than I indicate in the process, and to let the wheat soak 50 times longer in the solution, for it to be decidedly injured. By all that precedes, it has been seen that the bunt dust is composed of small spores, and that these behave quite like the seeds of the phanerogams. Now, M. Théodore de Saussure has demonstrated that, in general, salts are adverse to germination. Thus, it is not surprising that by dint of increasing the proportion of the sulphate, or the time of immersion, one succeeds in acting on the germ of the wheat; and, if there is nothing to fear for this germ from much smaller doses of sulphate, which nevertheless act so powerfully on that of bunt, this probably arises from the immense disproportion of the volume of the seeds, rather than from difference in their nature.

question of experimentation, it is better to use the cleanest seed obtainable. Nevertheless, I repeat, however contaminated the seed, the preventive will produce its effect.

178. In York County, England, as we have said (§169), arsenic is employed against bunt. They use only five grams for 14 hectograms of liquid, or four decagrams for each hectoliter of wheat. It will be objected, without doubt, that having said that the efficacy of arsenic against the germination of bunt is much inferior to that of copper sulphate, I nevertheless recommend a larger proportion of the latter.

But, (1) is it indeed certain that arsenic, employed as it is in York County, produces all of the effect that may be desired;[25] and if it is not employed in a stronger dose, is not this because the water can not hold more of it in solution in the process used, rather than because this dose suffices?

(2) Is not the effect obtained due in part to the large amount of stable urine that is added to the solution of arsenic?

(3) According to the experiments I performed on the germination of bunt, it is extremely probable that a quantity of copper sulphate, a great deal less than that indicated for the arsenic, would be sufficient; but I established the dosage that I recommend using upon the results of experiments I tried in the field.

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[25] I suspended some bunt in water that held in solution the same proportion of arsenic as the liquid in which the wheat is immersed in England to treat it; and I let it soak there for one hour and 10 minutes (A), for two hours and 20 minutes (B), and for four hours and 20 minutes (C), and then washed it.

Two and a half days after the germination should have begun, C had as yet produced nothing. Four days after this time, several aigrettes and some other stalks were at the surface. But the growth of A and B had only been retarded several days; and, moreover, had taken place, as usual, at the surface of the water.

At the same time I suspended some bunt in a solution of copper sulphate at the dosage I advise using, and left it here only 20 minutes before washing it. This sufficed to prevent it from germinating.

I have since proved that five minutes suffice for the preventive I recommend to produce more effect upon the germination of bunt than arsenic for four or five hours at the dosage prescribed by the English. We have seen that a solution of copper sulphate in water that contains only 1/10,000 of it by weight often suffices to destroy the germinability of bunt soaked in it for a half hour. I have proved that, in the same circumstances, four hours do not always suffice to produce the same effect in a solution containing 1/1,200 of its weight of arsenic. Thus, in regard to the time necessary for these two substances to act, as in the case of the intensity, the action of the copper sulphate is incomparably greater than that of the arsenic.

Moreover, although it is advisable, for this year at least, to adhere to this dosage, in order to be sure of success, I can scarcely doubt what would result from much smaller dosages, such as three decagrams, two decagrams, and even a single decagram, to each hectoliter of wheat. I tried this on several hectoliters of seed this year. The economy, after all, could never be very great, since, when the sulphate is bought at retail, it costs only 25 centimes, or 5 sous, per hectoliter.

179. Besides, there might be some particular cases in which it is possible that the preventive would not succeed; as, for example, if at the time of seeding, or shortly before or after, the wind brought upon the soil a large quantity of bunt from some neighboring place where wheat was being cleaned on a large scale. That, however, is extremely rare.

M. Tessier reports " . . . that, at the end of June, 1786, a farmer hauled into a piece of land that was to be sown in wheat in the following October, three cartloads of dust and débris from his barn, after having threshed his wheat, in which there were a great many bunted heads. This trash was left in three heaps for several months. At the time of the last working of the field, it was spread in the usual way, so as to leave as little of it as possible at the place of each heap. The remainder of the field was treated with ordinary manure. In 1787 half of the heads were bunted in the places where the trash from the barn had been left for a long time, a quarter in those upon which it had been spread, and none or very few in the rest of the piece of land. The same wheat and a steeping in lime and fowl's droppings (to seed the whole field) had been employed. The space manured by the trash occupied 15 to 18 rods."

The sulphate probably would not have protected these 15 or 18 rods; for, in whatever way bunt or bunted kernels come to be found abundantly upon the land, either when it is sown or some time after, it is not probable that the sulphate can protect, unless, perhaps, it is used in a very strong dosage.

180. Here the bunt and the bunted kernels were preserved intact in the three heaps. If it had rained much after the month of June, especially if, according to this supposition, the trash had been spread early, it is probable that all the bunt would have germinated too soon to be able to infect the wheat or that which

was contained in the bunted kernels would have become incapable of germination, as happened to that of the bunted kernels I kept for a long time under water. These facts agree perfectly with all that I have previously said concerning the cause of bunt and with what I conjecture concerning the final cause of the puccinias of the uredos, which are very probably retarded seeds, seeds that should not germinate until a long time after they have become detached from the plant on which they have grown. These facts likewise agree perfectly with what I have proved concerning the bunted kernels, which serve as retarded seeds of bunt. It is known, furthermore, that these delayed seeds are not without parallel in the phanerogams.

The Method of Using Copper Acetate on a Large Scale

181. Some vinegar is placed in a copper vessel, care being taken not to fill it, and left there 20 or 24 hours. It is then withdrawn and replaced with fresh vinegar in sufficient quantity to dissolve the verdigris, which is formed on the parts of the vessel adjacent to the liquid, and has not been wet by it. This solution is aided by rubbing with something appropriate. This new vinegar is added to the first, in order to make use of it, as will be explained.

But let us note (1) that the vessel should be clean, unless it be soiled by verdigris, or copper oxide or carbonate, which would then be dissolved by increasing the quantity of the vinegar;

(2) That, if the vessel is of large capacity, the vinegar should be put in only up to a limited height; otherwise, it would have to be left there longer, in order to enable it to acquire the desired property;

(3) That it is advantageous to cover the vessel while the vinegar remains in it, and to stir it from time to time, although this precaution is not indispensable;

(4) A part of this solution is mixed in four, five or six parts of water, according to the strength of the vinegar that has been employed, and it is used to moisten the wheat, as has been prescribed for the sulphate. But I forewarn that this process has not been proved upon wheat and that copper sulphate, a specific of which I have assured myself by a much greater number of experiments, is much more valuable, is generally cheaper, and is not

subject to any disadvantages. I propose the acetate only for those who might not be in position to procure the sulphate when needed.

Lacking large copper vessels, one may put into wooden vessels, with the vinegar, the débris of copper utensils, or copper coins, which will not undergo perceptible change (§165).

Limings

182. M. Tessier, after having tested a large number of different substances as preventives of bunt, proposes four methods in which lime is the principal ingredient. According to him, this substance is the only one that acts efficaciously: "Without lime (p. 712), none of the recipes that have been proposed against bunt would have well-marked effect: it is the lime that gives them this degree of activity so necessary to purify the seed from the contagious dust. Thus, it is always recommended to pass the seed through lime, in whatever manner it may be advised to treat it otherwise." He seems to compare its efficacy relative to bunt to that of cinchona against the intermittent fevers. "However, it sometimes happens that with the best recipes one does not succeed, and it is probably because the lime is not good[26] or because it is not used properly and not reinforced by indispensable care. Moreover, when the wheat in the sheaf is full of bunted heads, or when the threshed grain is suspected of being or is perceptibly contaminated by bunt, much is risked by being content with liming it. I have sometimes been fortunate enough to harvest no bunt at all from fields, the blackened and contaminated seed of which had been subjected only to a most careful, long, and perfect liming. But I have not succeeded completely every year; it is surest then to precede the liming by one of the following treatments:"

183. These treatments are of six kinds:

(1) Cleansing by hand selection. This is the simplest. In 1790, within a radius of 45 to 50 miles of Paris, when the bunted heads were not too numerous, and by having this work done by women, it cost about 12 sous per hectoliter of seed.

(2) Cleansing by threshing the bunted stems upon a cask or a cylinder.

[26] It has recently been found that lime cooked with wood contains much potash, which should render it more active in liming than that cooked with coal.

(3) Cleansing by threshing with a flail with powdered earth.

(4) Cleansing by milling.

(5) Cleansing by sifting.

"Nothing is more expeditious for sifting," says M. Tessier, "than small wire. Disposed in an inclined plane, and formed of iron wires pressed taut against one another, it receives the grain from above, and the latter reaches the bottom only after having been shaken and battered about. By repeating this operation several times, the black color may be entirely removed.

"In 1782, in order to learn what degree of cleansing could be obtained by this means, I sowed some wheat that had been very much contaminated with bunt, but had been passed 12 times over an iron wire sieve, and some of the same wheat that had been passed 30 times over this sieve. The latter was so thoroughly cleaned that there was no longer occasion to hope that further sifting would clean it more; it could be shown to advantage in the markets. The first yielded 25 bunted heads per sheaf, and the second only 11,[27] that is to say, less than half as much. In the same year, unsifted wheat produced 1/4 of bunted heads. It is then proved that siftings, more or less often repeated, purify the wheat of more or less of the bunt, without wholly removing it."

(6) Cleansing by washing in water.

"It is not necessary," says M. Tessier, "to use very cold water, which would shrivel the grain, instead of cleaning it. Warm water succeeds much better. The washings do not remove all sources of bunt. I have sown wheat after having washed it in three and in six waters. The first produced one-fifth, and the other one-eighth of bunted heads. The same wheat, sown without being washed, yielded more than one-fourth of bunted heads." (*V.* §137.)

M. Tessier cites a method of M. Girot, which seemed to him exact and sure (p. 716).

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[27] The bunted heads often stand very low, as M. Tessier has observed; so that a large number escape the sickle and remain in the stubble. It is not possible, therefore, to judge the true proportion of healthy and bunted heads by the grain in the sheaf. But this experiment proves, nonetheless, that the more the wheat is passed over the sieve, the less it is contaminated. I mean only that it must not be concluded from it that the number of bunted heads in the field in the first case was only 25 per sheaf, or only 11 in the second.

184. He is convinced that, without these preliminary operations, liming does not succeed. "Several times," he says, "I have succeeded in harvesting wheat free from bunt by employing only simple liming; but this was in years in which the seed wheat was only slightly contaminated. In 1785, I divided a field into nine parts. Wheat almost entirely black with bunt was sown here, after eight portions of the seed had been steeped in different doses of lime. These lots of seed produced a great quantity of bunted heads, some one-fifth or one-fourth, others one-third or even more. At the harvest of 1786, the wheat that had been subjected to no treatment, did not yield more bunt. I had placed the seed of the ninth part in a bucket full of lime water, in which it soaked for 24 hours. I found in its yield only 1/25 of the heads bunted.

185. "It follows from this experiment, (1) that liming alone cannot protect from bunt the yield of wheat from seed highly contaminated with it; (2) that when it is contaminated to a certain degree much care is necessary to put it in a state of adequate purity; (3) that, if absolutely necessary, by letting it soak a long time in lime water, the contagious principle would be almost entirely killed. But it would be necessary to skim off the bunted kernels, which, without this attention, would continually be crushed in the manipulations of liming, and would give the wheat the disease from which it is sought to free it; and, yet, there is no assurance that some of these would not escape the most scrupulous search."

186. Let us note here that, when I advise removing the bunted kernels carefully when the wheat is passed into the copper sulphate, this is not for fear of their being crushed in the solution. On the contrary, I am quite sure that, if it remains there for some time, the dust of all those that are crushed will lose its viability, and consequently, no longer be contagious. I fear only that the intact bunted kernels may later be crushed in the treated wheat, either infecting it anew or being scattered upon the field with the seed. There would be nothing to fear even from these bunted kernels if they had soaked five or six hours in the solution, or only one hour in a solution twice as strong. They would then be sufficiently penetrated by it for the gemmae they contain to be incapable of germination.

187. M. Tessier has noted "that a large number of landowners and farmers protect themselves from bunt by using only lime and water in a large dosage." "As for myself," he adds, "I have employed this method only in large-scale cultures and in years when the contagion of the bunt was very widespread, and harvested scarcely any bunt." It should be understood, to be sure, that the seed had been cleansed before being limed. Otherwise, this would not seem to accord with either what precedes or what follows: "When in some comparative experiments," he continues, "I used more or less attenuated dosages of lime, I had more or less bunt. . . . But in this case the wheat had been *well sifted and washed* before being limed; for if various proportions of lime were tried upon seed that was much contaminated with bunt, without a previous cleansing, the seed treated with a strong dose of lime would produce as many bunted heads as that treated with a weaker one. I have at least tried it by weakening the proportions up to one-eighth. The reason for this is simple. It is that when the seed is so contaminated that it is black, whatever the quantity of lime employed, it removes only a part of the bunt, and much always remains. Not all of the dust is active in the production of bunt but only a small portion of it. So long as this portion remains, one should expect to harvest many bunted heads. Now, in the circumstances in question, lime and any other substance that may be added to it, exerting their action upon the greater part of the *bunt*, would not attack the dust that adheres closely to the wheat kernels, and its full effect would take place, which proves further the necessity of a cleansing."

188. It seems to me that this explanation is satisfactory only in so far as one supposes that the action of the lime on the bunt is purely mechanical; that it forms upon the seed a crust that, in becoming detached, carries with it a part of the bunt, an effect that may take place up to a certain point when it is used in large dosage. But, although the lime has only a quite weak chemical action upon the germination of bunt, it has one, nevertheless; and, in general, bunt does not germinate at all, or germinates very poorly, in filtered lime water. But, if it is allowed to soak in it for a few hours and then washed, it germinates about as usual. If it is soaked a long time, its germination is retarded or diminished, and a greater or less part of the gemmae lose their

germinability. It would seem, therefore, that, in addition to its mechanical action in removing bunt, lime must also destroy the germinability of a certain portion of the gemmae that adhere to the kernels.

189. But if the lime acts only mechanically on bunt, or if its chemical action on the germination of this seed is so weak that it is able to produce a very marked effect only under certain conditions and after a long time, this is not true of several other substances and particularly of copper sulphate. It suffices for bunt to soak a few minutes in a solution containing only 1/100 of its weight of this salt to lose its germinability irrevocably; but, in order that this effect take place in such a short time, the bunt must disseminate or become suspended. The gemmae compressed within the bunted kernels, being unable to dilate promptly enough to take up the solution, do not become disorganized, unless these bunted kernels soak for a longer time, or unless the solution is stronger. However, this is not so true for the gemmae that are at the surface of the wheat as it is for those that are enclosed and compressed within the bunted kernels. As soon as the wheat seed is well moistened, these gemmae are, necessarily, also wet; and, thereafter they soon lose their ability to germinate or propagate bunt.

190. In the first of the four methods of M. Tessier, the lime is used only with water;

In the second it is used with some neutral salts;

In the third with volatile alkali;

In the fourth with fixed alkali.

In the first three methods 20 pints of water are used per hectoliter of wheat,[28] and in the fourth, 25 pints.

In 1790, in the vicinity of Paris, the ingredients of the first method cost 25 centimes, or 5 sous, per hectoliter; those of the second and the third, 20 centimes, or 4 sous; those of the fourth, 70 centimes, or 14 sous.[29] This does not include the price of the

[28] M. Tessier says, p. 725, that to wash 24 bushels [two setiers, Parisian measure] of wheat in lye according to this method, one bushel of pigeon droppings, etc., must be placed in 260 pints of water; and, on page 729, he indicates by the same method only 3,250 pints of water for 1,200 bushels. He must be mistaken in one place or the other; for, if 24 require 260, 1,200 will require 13,000. Perhaps instead of 260 it should read 60, or rather 65, or 96 bushels instead of 24.

[29] M. Tessier says, page 731: "All being well calculated, one is able, in the

preliminary cleansing, which is indispensable when the wheat is visibly contaminated, and the simplest method for which, as we have seen (§183), cost 12 sous per hectoliter in 1790; nor take into account the cost of the fuel used to heat the water as is prescribed, or even to boil it,[30] sometimes with several repetitions.

The surest way of using these limings is to let the wheat soak for 24 or even 48 hours. In the third method, the pigeon or fowl droppings, which furnish the volatile alkali, must soak for 15 days in water, and this preparation has the disadvantage of having a very bad odor.

In order that a preventive may be generally adopted, it must be extremely simple and inexpensive. One can scarcely regard as combining these advantages treatments in which a large quantity of boiling water must be used, which are so precarious in their effectiveness that they act certainly only by means of long or expensive preliminary cleansings, such as washing in several waters or oft-repeated siftings, and that require the wheat to remain in them for 24 or 48 hours. The method I propose, copper sulphatation, requires nothing else, even for the most contaminated seed, except that the seed soak for a half hour in a solution that is easily prepared cold. Moreover, the manner in which this is done is not important. I require, furthermore, it is true, that this seed be freed of whole bunted kernels, or that they be removed during the operation; but that can be done by extremely simple means that are at the disposal of all farmers.

191. However, M. Tessier's preventive methods, which were without doubt the surest and most convenient of the time in which he wrote, should be studied in his own works. On the basis of what he himself says of them, they should be compared

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vicinity of Paris, to lime 12 bushels of wheat for 8 sous, employing the most expensive method, that in which the lime alone is dissolved in the water."

But the most expensive liming, it seems to me, is the one the price of which is given, page 730, at 107 francs 10 sous, the 1,200 bushels, Parisian measure, or 21 sous 6 deniers per 12 bushels and in which the lime is combined with fixed alkali.

[30] I prescribe, it is true, dissolving the sulphate in a little boiling water when one is in a hurry. But this may be dispensed with, and the solution will be retarded only three or four hours.

with sulphatation, which, I think, is infallible, much simpler, and less expensive.

192. I have been led to this by the discovery of the direct cause of the disease, which I have followed with care and described in great detail. The new method that I have found of studying internal plants, or rather, these amphibious species whose development begins in the open air and finishes within the body of other plants, has led me to some observations that may be of interest in natural history, and has given me the occasion to point out some errors concerning the nature of these microscopic organisms.

The success unfailingly obtained by those who have tried or will carefully try the copper sulphate treatment should cause its general adoption. But, even if it were practiced by only a small number of careful farmers, the wheat that they would harvest, being absolutely bunt-free, might, without need of any treatment, serve to propagate pure seed, and to extirpate the germ of the infection from the soil of the Empire.

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EXPLANATION OF FIGURES

Plate 1

Fig. 1. Fully mature, dry bunt globules.
Fig. 2. Globules that have soaked for some time in water; some appear to be attached to filaments, with which they form a sort of cluster.
Fig. 3. Bunt globule or gemma, beginning to put forth a bud.
Fig. 4. This bud becomes a small stalk, which is elongated in figs. 5, 6, 7, 8, 9.
Figs. 10–11. Stalks forked or bearing an antler-like structure.
Figs. 12–21. The origin and formation of the aigrette.
Figs. 22–25. Aigrettes that have fallen into the water, after having begun to form in the air.
Fig. 26. Aigrettes seen by reflected light and less magnified.
Fig. 27. Tuft-like or stupose stalk.
Figs. 28–32. Plumose stalks bearing fruits of some kind.
Fig. 33. Early development of a tuft-like or stupose stalk.
Fig. 34. Another mode of development of stupose stalks.
Fig. 35. Late development of an aigrette.
Fig. 36. Empty globule, much enlarged, after putting forth a long stalk.
Figs. 37–38. Last observable developments of the shoots or secondary stalks that make up the stupose stalks.

Plate 2

Figs. 1–8. Much enlarged pistils and stamens of a very young bunted head.
Fig. 9. A much more advanced flower.
Fig. 10. Flower of a healthy head ready to appear.
Figs. 11–14. Bunt globules, such as are found in very slightly advanced embryos.
Figs. 15–18. More nearly mature globules.
Figs. 19–20. Globules that seem to be implanted upon a solid substance.
Fig. 21. Globules or gemmae that are beginning to become opaque.

Plate 3

Fig. 1. Globules such as are often seen in the embryo of healthy wheat. They appear to be flattened, and are very different from those represented in Plate 2.

Fig. 2. Globule that is sometimes found with the eel vibrio and other vibrios in kernels of wheat that have produced stalks several inches high.

Fig. 3. Bunted head with elongated, hollow kernels. Similar heads without bunt are sometimes found, the kernels of which are empty.

Fig. 4. Seeds from the same head, detached and slightly enlarged.

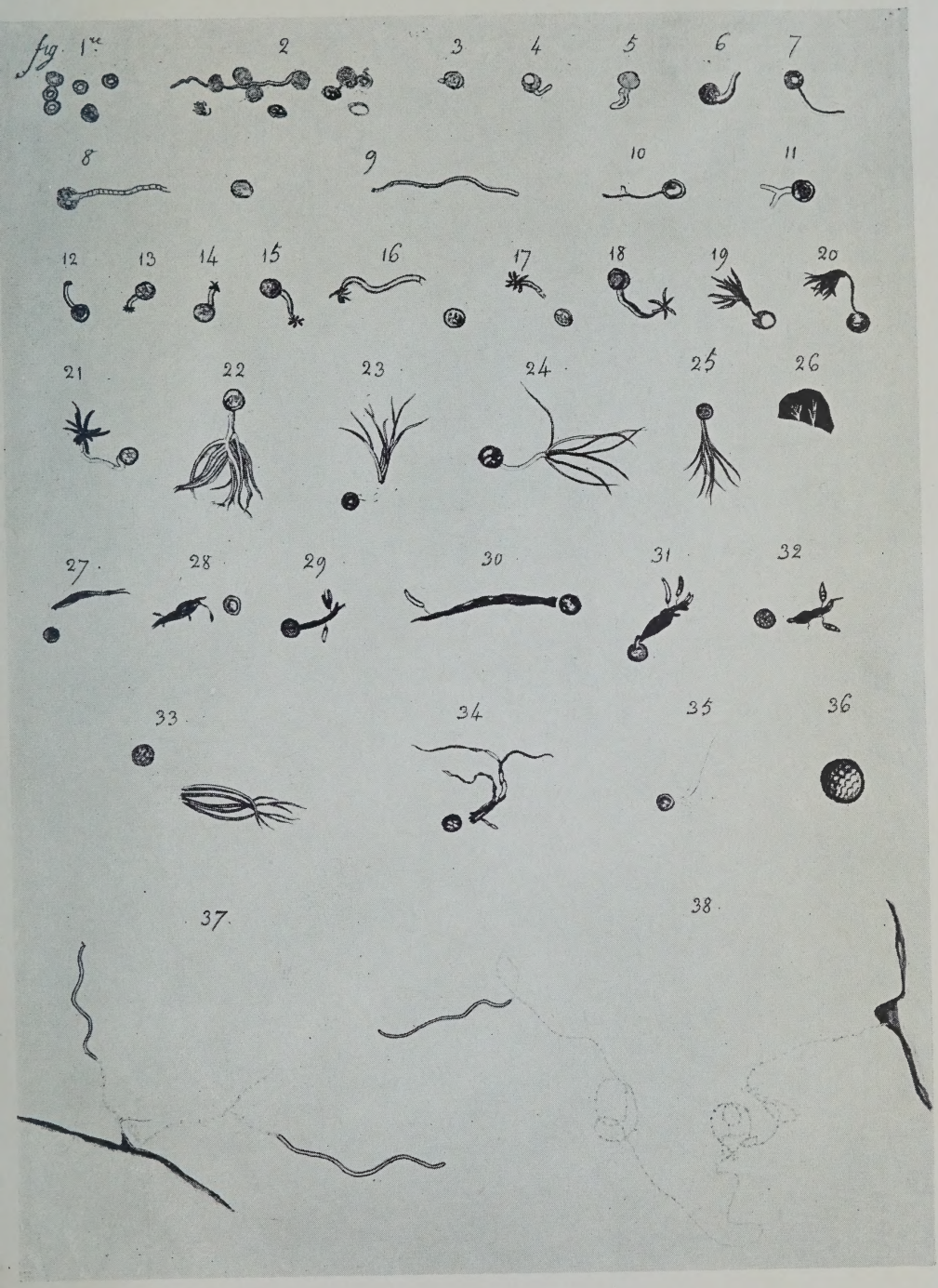
Fig. 5. A bunt stalk of unusual shape, developed from gemmae found in the kernels of the preceding figure.

Figs. 6–7. Extremely young initial of a smutted or blighted head, enlarged with the magnifying glass and the microscope.

Fig. 8. Much enlarged clusters of globules or puccinias of smut or blight, found in similar but more advanced heads.

Fig. 9. Globules that become detached from ergot of rye or other gramineous plants, and, at a slightly raised temperature, become active and put forth stalks.

PLATES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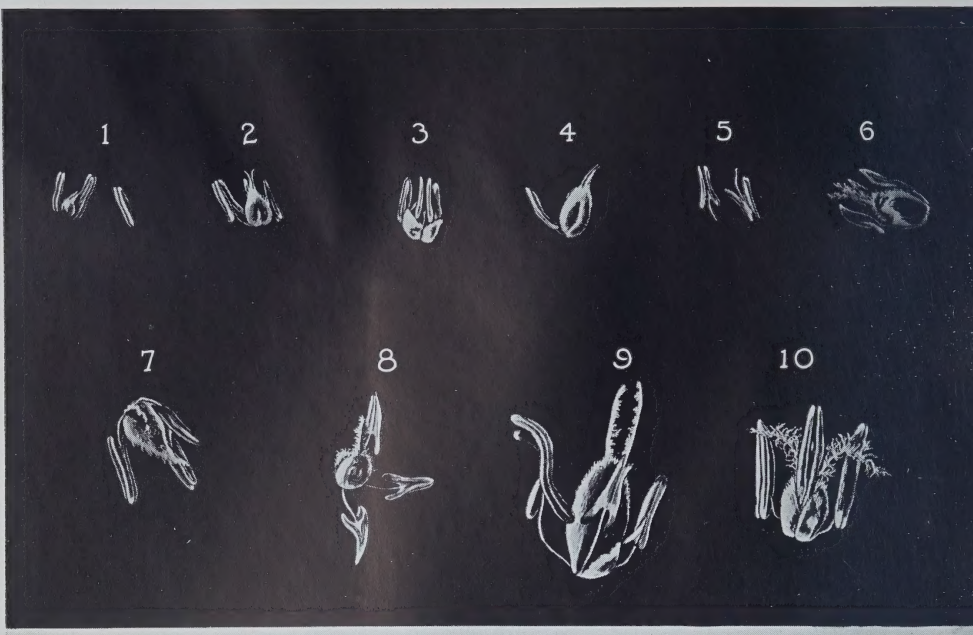
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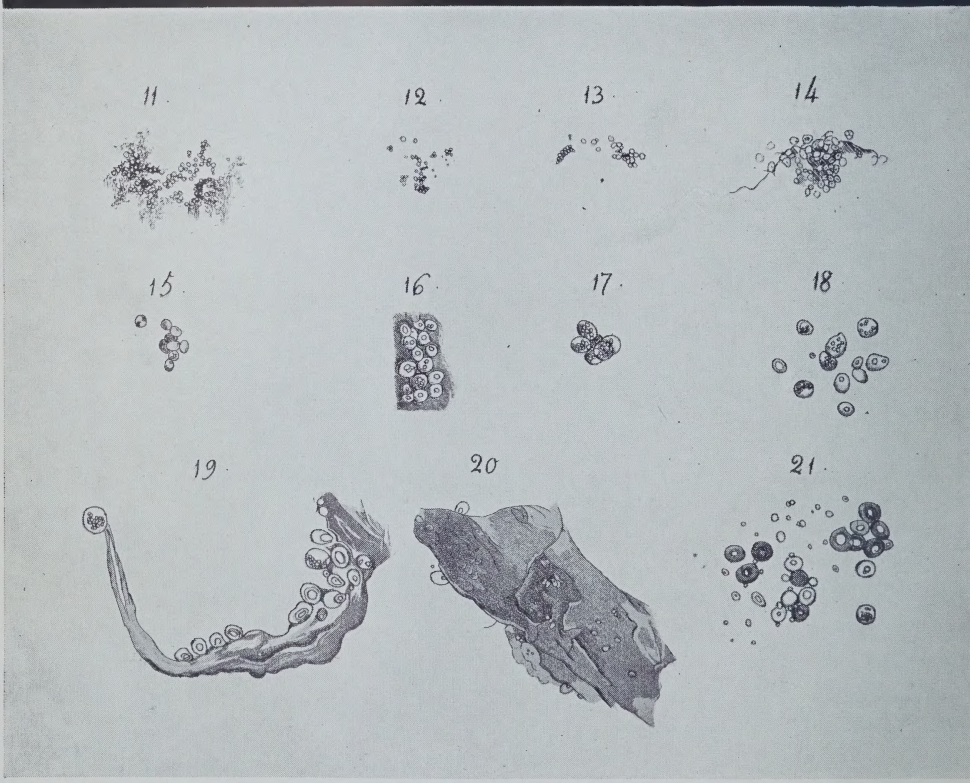
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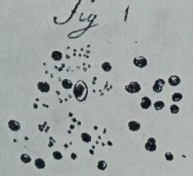
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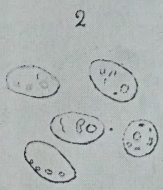
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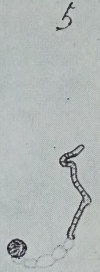
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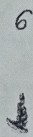
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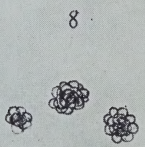
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